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EFFECTS OF WHOLE AND PARTIAL BODY EXPOSURE TO DRY HEAT ON CERTA--ETC(U)
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TECHNICAL REVIEW AND APPROVAL

AMRL-TR-80-43

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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This study evaluated the effects on four performance measures of air of 65.6 C when the head was cooled with air of 15.6 C and without head cooling. Six subjects were exposed for 66 minutes to these environmental stressors and to two benign control tests. Humidity for all tests was maintained at 10 mm Hg partial water vapor pressure. The performance measures were (1) mental arithmetic accuracy, (2) choice reaction time, (3) position compensation tracking, and (4) rate compensation tracking. The tasks were presented in a repeating sequence throughout preexposure and exposure tests.

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Performance on all tasks showed the effects of the passage of time related to the gradual onset of fatigue. Preexposure reaction time performance and rate compensation tracking were better in the afternoon than in the morning. Performance on all tasks except position compensation tracking was influenced by differences in subject arousal level as indicated by body temperature measurements. The relationship between arousal level and reaction time stimulus information level was particularly pronounced. No indication was found of a heat influence on tracking task performance. Head cooling did not exert a significant influence on either tracking task.

SUMMARY

The objective of this research was to determine the time course of effects of two environmental heat stressors on four human performance measures. Six right-handed male Air Force personnel repeatedly performed four tasks during 66 minute testing periods under four thermal conditions. Data were collected twice under each condition, once in the morning and once in the afternoon. The thermal conditions were (1) a benign control (26.6°C); (2) a benign condition where the head and neck were ventilated with air of the same temperature (26.6°C); (3) a heat stress condition (65.6°C); and (4) a heat stress condition (65.6°C) where the head and neck were ventilated with cool air (15.6°C). Humidity was maintained for all conditions at 10 mm Hg partial water vapor pressure.

All tests were conducted in the constant temperature "All-Weather Room" chamber at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Air motion turbulence varied in flow rate up to 8 meters per minute. The ventilating helmet was a round, double-walled, plexiglass chamber into which air was introduced through insulated tubes. A rubber neck ring provided a positive seal between the helmet and subject. Air was introduced through a perforated ring at the base of the helmet at 5 cfm. The weight of the helmet assembly was counterbalanced. The overall noise level within the chamber was 69 dB; during the conditions involving head ventilating the subjects wore earplugs to attenuate increased noise.

The four performance measures were (1) mental arithmetic accuracy, (2) position compensation tracking,(3) choice reaction time, and (4) rate compensation tracking. The mental arithmetic task was a subject-paced sequential addition and number comparison paper and pencil design. This was the first task administered at each trial, begun at 5 minutes after entering the chamber. It was repeated at +29 minutes and again at +63 minutes. The choice reaction time task was an experimenter-paced, stimulus-controlled response, measurement of a 1:1 mapping of stimuli onto responses. Two dependent variables were measured to the nearest millisecond. These were reaction time and movement time. The signals for the two tracking tasks were presented on a 4-inch CRT mounted at eye level 50 cm from the eye. Tracking control was afforded through a rigid force stick. Both tracking tasks were single-axis, closed-loop divergent systems where the divergent was constantly varied on a ramp input and contained a positive error-rate feedback loop. The dependent variable used for both tracking tasks was an estimate of the subjects' effective time constant.

Performance on all tasks was worsened due to the gradual onset of fatigue. The fatigue effect also showed in the subjects' information processing. However, the onset of fatigue was not pronounced in the benign and heat ventilated tests. Performance on the reaction time and rate compensation tracking task was better in the morning than in the afternoon. These differences were probably related to arousal level differences in the subjects. This arousal level influence also appeared in mental arithmetic and reaction time task performance. The speed of choice reaction time responses, but not the accuracy, was increased in heat. The influence of arousal differences on information processing to choice reaction time performance held throughout for responses to one bit and two bits stimuli. It held for 50 inches for responses to three bits stimuli. Thereafter, responses to the greater information content were slowed by the over-arousal effect of heat. Under-arousal, as indicated by core temperature differences, caused a slowing of responses to the one and two bits stimuli in the benign-ventilated tests. Mental arithmetic accuracy deteriorated in the closing moments of the conditions involving a heat stressor.

The regression of reaction time measurement associated with the stimulus information content did not hold under all environmental conditions. The use of cool air to ventilate the head was effective in ameliorating heat influences on reaction time performance. Cooling the head counteracted the influence of the heat stressor resulting in overall performance being quite similar to benign performance. This was not true when the head was ventilated in the benign condition. In the final measurements of these tests, a negative slope was found. This indicated that reaction to higher information content was faster than to lower information content. This probably resulted from the under-arousal of the subjects at those times. The movement time component of choice reaction time showed no consistent relationship to the information level of the stimulus.

Position compensation tracking was very stable. It showed the influence of fatigue but was not sensitive to the other variables in this study. Rate compensation tracking was a sensitive measure of investigation variables. It was clearly sensitive to diurnal differences and to fatigue effects of the passage of time. It may also have been sensitive to heat effects of the magnitude used in this reasearch since heat was found to be significant at the 10% level. This may have been a result of the differences in arousal level induced by the environmental head load on the subjects.

PREFACE

The research reported herein was performed in the Barothermal Branch, Environmental Medicine Division of the Aerospace Medical Research Laboratory. The author was an Air Force Institute of Technology student at Purdue University when the data were collected.

The author expresses his appreciation for supporting efforts by personnel of the Aerospace Medical Research Laboratory: Dr. Abbott T. Kissen who assisted in the study design and collection of data, Dr. Adolph R. Marko and Mr. David A. Ratino who constructed the experimental apparatus, Mr. Robert Bachert who assisted with the statistical analyses; and he acknowledges the support of the late Mr. George C. Frost for his advice on the design of the tracking tasks. Appreciation is also given the following Purdue University faculty for their counsel, guidance, and assistance in the design of the study and interpretation of data: Dr. Arthur L. Dudycha, Dr. Barry H. Kantowitz, Dr. N. M. Downie, Dr. Ernest J. McCormick, and Dr. Robert D. Pritchard.

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INTRODUCTION

Man-machine systems must, at times, be operated under hyperthermic environmental conditions hostile to man. Cabin temperatures of operational aircraft have been found to exceed 65.6°C even though the ambient temperature was only 43.3°C (Sandstrom, 1966). Failure of the environmental control system on supersonic aircraft would allow cabin temperature to rise rapidly due to more than 315°C heat which builds up on the outer edge of the canopy (Stone, 1969).

Research on performance in hyperthermal environments has revealed that by maintaining the head and neck in thermal comfort the physiological stress associated with the stressor level can be reduced. This has resulted in longer tolerance to the stressor with attendant comparative prolongation of the ability to perform in hyperthermic environments (Kissen et al., 1974; Konz and Kentwich, 1969; Shvartz, 1970; Shiratori et al., 1963). Two studies reported effects of head cooling on the types of performance that might prove critical for vehicular control (Clifford, 1965; Kissen et al., 1974). In these studies, conductive cooling was provided by circulating water.

One purpose of this research was to reduce the potential contribution of humidity to the hyperthermic stressor through exposure of subjects to dry heat. In this research performance on several cognitive and motor tasks was examined in two steady-state thermal environments. These were a benign environment (26.6°C) and a high temperature (65.6°C) environment. Performance in these environments was evaluated with and without the effects of head cooling, using circulating air as a coolant medium.

The objective of this research was to determine the time course of effects of two environmental heat stressors on four human performance measures: position compensation tracking, rate compensation tracking, choice reaction time, and mental arithmetic accuracy. The environmental stressors employed were unprotected exposure to high temperature heat and exposure to the same heat environment where the subjects' head and neck were cooled by circulating air. Specific research objectives were to determine the time course of performance changes and to evaluate such changes in terms of alterations in information processing capabilities of the subjects. In addition, a specific objective was to compare the effects on performance of head cooling to the unprotected thermal stressor.

REVIEW OF THE LITERATURE

Where the time and temperature levels of exposure to hyperthermic stress have tended to approach the physiological tolerance levels, consistent performance decrements appeared (Wing, 1965). This is not to imply that changes in performance do not appear before this. However, such earlier changes occasionally result in improved performance, although the common change is toward greater variability without appreciably changing the mean levels. An excellent summary review of research on human performance was presented by Grether (1973). His paper converted data from different studies involving performance measures similar to those considered in this study to a common graphic presentation for ease of comparison. He converted thermal condition data to Effective Temperature to make such comparisons. This approach was also employed by Wing (1965) in an earlier summary review on mental performance decrements.

Heat exposure causes greater movement activities. The movements are initially slightly quicker, and later in the exposure slower than in preexposure benign environments. This was reported for reaction time (Kleitman et al., 1938; Fraser and Jackson, 1955) and tracking performance (Pepler, 1960). Heat causes, at least initially, a tendency to respond more quickly, though generally with less accuracy. This was observed in subject paced position prediction (Bartlett and Gronow, 1953), signal detection (Wilkinson et al., 1964; Poulton and Kerslake, 1965), self-paced complex tests (Allnutt, 1969), reaction time (Kleitman et al., 1938; Broadbent, 1963; Pepler, 1959), and tracking (Pepler, 1958, 1960). In tasks requiring coordinated eye-hand manipulation, the tendency to respond more quickly diminishes with time. As the subjects approach their physiological tolerance, t ne to respond in heat become longer than it was in the preexposure environment and the number of errors becomes progressively greater. This effect appears with both reaction time task performance (Pepler, 1953; Fraser and Jackson, 1955; Azer et al., 1972) and tracking (Blockley and Lyman, 1951; Pepler, 1959).

Heat may sharpen attention to mental tasks while simultaneously reducing capacity to handle multiple or complex stimuli, perhaps through limitations on short term recall. This was observed for tasks of auditory and visual vigilance (Pepler, 1958; Wilkinson et al., 1964; (Colquhoun and Goldman, 1972), auditory recall (Wing and Touchstone, 1965), speeded symbol discrimination (Pepler, 1958), telegraphy signal interpretation (Pepler, 1953; Mackworth, 1950, 1961), mental addition (Wing, 1965), and mental addition to a referenced total (Blockley and Lyman, 1950).

In heat stress performance studies at least two factors contribute to changes in subject arousal level—the thermal stressor, and the task itself. A high temperature environment besieges the body with stimuli that call forth a wide range of physiological responses. Although the effect on the subject to these stimuli is largely involuntary, the cardiovascular physiological responses are typical of those associated with increases in arousal (Poulton, 1970). The demands of the task itself also contribute to changes in arousal, but such demands are not unique to heat stress studies.

In 1966, Provins suggested that changes in performance under thermal stress were due to alteration in the arousal level of the subject, that was directly related to the body temperature. Subsequently, he modified his position to suggest that "...arousal level is not simply determined by, or directly related to, absolute body temperature,..." as he originally postulated. At any rate, such effects as there may be of absolute body temperature on arousal are relatively small compared with those of the relationship between skin and body temperatures, and changes in this relationship." (Provins et al., 1974, p. 64) Poulton and Edwards (1974) suggested that arousal probably increases while a person is being heated, as implied in the work of Poulton and Kerslake (1965) and again when the person is uncomfortably hot, as suggested by the work of Wilkinson et al. (1964) and Colquhoun and Goldman (1972). Thus, there is no readily available metric to describe accurately the probable contributing factors.

Effects of stress do not arise suddenly at some point where coping becomes impossible, but rather appear as a continuous variable, increasing gradually as demand approaches a person's maximum capacity or willingness (Welford, 1974). The absence of a performance shift with heat stress is not an indication that heat has not produced an effect. The maintained quality or quantity of work output may have been made possible at an increased cost to the subject in terms of effort put into the task (Provins, 1966). Such task quality maintenance is sustained through increased use of the subject's spare capacity (Kahneman, 1973). It is only when the level of arousal exceeds the optimum value for performance on the task concerned that the increase in body temperature arising from the insult of the thermal stressor results in altered performance (Colquhoun and Goldman, 1972).

The literature suggested that performance on the mental arithmetic tasks employed in this research was likely to be affected by the heat stressor being used. Where the task metrics are sensitive to accuracy of performance and the exposure time is fairly lengthy, decrements in performance typically have been found in heat stress environments. Blockley and Lyman (1950) found clear indication of mental arithmetic performance decrement under heat and time conditions quite similar to those employed in this research. Givoni and Rim (1962) found performance decrements towards the end of their tests. Fox et al. (1963) found mental arithmetic performance to be affected by variations in body temperature. The implications from the literature about the influence of head cooling are less clear. Studies reported by Konz and Kentwich (1969) and by Kissen et al. (1974) did not indicate performance change. However, both used lower heat levels than those employed in this research and Konz and Kentwich used mental arithmetic productivity as their dependent variable. Moreover, the literature suggested that differences in mental arithmetic accuracy performance may be related to subject arousal level. This was supported by the work of Givoni and

Rim (1962) and by Fox et al, (1963) and by the conclusions of Wulfeck and Zeitlin (1962) who reanalyzed a 1946 study reported by Viteles and Smith. Therefore, head cooling may influence mental arithmetic accuracy if the ventilation alters the arousal level by cooling the body.

The literature reviewed on choice reaction time suggested that the reaction time component of the choice reaction time task would likely be affected by the heat stressor used in this research.[1] Kleitman et al. (1938) found that both simple choice reaction time was affected by body temperature changes induced through diurnal influence. Fraser and Jackson (1955) found differences in serial reaction time performance in a high humidity, moderate temperature stress study. Bursill (1958) studied responses to a simple reaction time task performed simultaneously with tracking under temperature conditions of 35°C. Azer et al. replicated the Bursill study in 1972. Both reported that reaction time was lengthened and the errors increased in heat stress when the tracking task was a fairly demanding one. In 1971 Grether et al. found that choice reaction time was lengthened when performed simultaneously with tracking in 48.9°C heat. No studies of the effects of head cooling on reaction time performance have been reported. However, in 1971 Benor and Shvartz employed a forewarned simple reaction time task while cooling the whole body. No effects were found in this study for either the heat stressor alone or for cooling when compared to heat performance. The stressor employed was as great as 50°C. The subjects performed under heat until exhausted and under heat and body cooling for 2 hours. This suggests that effects of heat on reaction time task performance may be related to the difficulty of the task.

Performance changes may result from variations in internal body temperature above or below that normally maintained. Reduction in normal body temperature, by even the slight amount resulting from diurnal variation, was suggested by Kleitman et al. (1938) to influence performance adversely. Thus there has been some support from the literature for performance change due to head cooling or other partial body cooling. However, this inference is tenuous since few have found significant differences shortly after subjects were exposed, during which time there is generally a drop in core temperature. This effect is one of a short time duration, however, and few studies have involved performance time measurements during the first moments of exposure that might reveal such an effect. Decrements in performance resulting from heat stress appear after the environment has been tolerated for a time. This is consistent with the concept of arousal being an inverted-U function. There would have to be a change in body temperature sufficient to alter the arousal level enough to cause a performance decrement.

The effects of heat on the movement time component of choice reaction time must be surmised. The studies reviewed did not specifically address movement time, but rather considered it as a part of the overall reaction time. The studies of Kleitman et al. (1938), Fraser and Jackson (1955), and Azer et al. (1972) suggested that movement time may be initially faster under a heat stressor, but that later in the exposure it is likely to slow. To the extent that performance changes are related to variations in arousal level, it is possible that cooling of the head while the subject is exposed to a heat stressor may counteract the influence of heat.

The tracking performance literature suggested that heat would likely influence tracking behavior adversely towards the end of an exposure period, particularly for tasks with taxing dynamics. In 1969 Iampietro et al. employed two-dimensional compensatory position tracking with simultaneous additional monitoring and arithmetic tasks. They found no differences in the vertical dimension under the influence of heat. They did find differences in horizontal tracking, but that may have been due to the cross-coupling of the tracking hand with responses required to the other tasks. These findings, therefore, are not relevant to this research. Moreover, in that study, the exposure period was about one-half that used in this study. In 1971 Grether et al. used a two-dimensional position tracking task in 48.9°C. Performance on that task was performed simultaneously with both choice reaction time and voice communication tasks. Vertical tracking performance was found to be affected by heat. Horizontal tracking may also have been affected; the significance level observed for horizontal tracking was at the 10% level. Azer et al. (1972) employed position compensation tracking in 37.8°C heat; they reported performance deterioration at the end of a one-hour exposure. Smiles et al. (1975) exposed subjects to a heat level of 50°C. In those tracking tasks involving relatively stable forcing function dynamics, they observed that hits-on-target were slightly better under heat, but that there was no change in the subject describing functions that were derived. However, when the task involved an unstable plant dynamic forcing function, and was therefore a difficult task, performance definitely worsened. The describing function showed changes under heat in gain, phase angle curves, and bandwidth. This suggested a higher frequency over-control response characterized by more rapid but less accurate control movements.

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[1]The reaction time component of performance on a choice reaction time task was operationally defined for this study as the elapsed time from presentation of a stimulus signal until the subject begins a movement response. The movement time component was that time elapsing from beginning a response movement until the response device was activiated.

METHOD

Six right-handed, male, Air Force personnel repeatedly performed four tasks during 66-minute testing periods under four thermal conditions. They were tested twice under each thermal condition, once in the morning and once in the afternoon. The thermal conditions were (1) a benign control (26.6°C); (2) a benign condition where the head and neck were ventilated with air of the same temperature (26.6°); (3) a heat stress condition (65.6°C); and (4) a heat stress condition (65.6°C) where the head and neck were ventilated with cool air (15.6°C). Environmental humidity was maintained for all conditions at 10 mm Hg partial water vapor pressure. The subjects' physiological state was continuously monitored throughout each test. All subjects had been exposed to identical thermal stressor conditions in previous research.

Before each test the subjects performed a prescribed practice on the tasks outside the chamber. All subjects had been trained to asymptotic proficiency on all tasks before the tests were started. During each test the subjects wore physiological monitoring sensor devices, clothing of approximately 1 clo insulation, and a cotton glove on the right hand. During the conditions involving head ventilation, the subjects wore BILLESHOLMS mineral wool earplugs to compensate for increased noise. The physiological monitoring systems were calibrated for all subjects before the start of each test. Shortly before entering the environmental chamber, subjects were required to void their bladder and to drink 600 cc of water.

All tests were conducted in the constant temperature "All-Weather Room" at the Aerospace Medical Research Laboratory. Temperature within the chamber was controlled by heating or cooling air introduced into the chamber. The chamber was brought to prescribed temperature and humidity levels approximately one hour before the start of a test. Humidity was controlled by passing ambient air across refrigerating coils, which allowed water vapor to be condensed and extracted. The dried air was then heated by passing it across banks of electrically heated coils in the ducts leading into the chamber. If necessary, water vapor could be added by venting steam into the ducts. Air motion turbulence within the chamber varied in flow rate up to 8 meters per minute. The overall noise level within the chamber at this flow rate was 69 dB.

A special helmet was used to provide the necessary microclimate for those tests where the head and neck were ventilated. The helmet was a double-walled, round, plexiglass chamber into which air was introduced through insulated tubes. A rubber neck ring provided a positive seal between the helmet and a subject. Air was introduced from a controlled source through a perforated ring at the base of the helmet at 5 cfm. This air bathed the wearer's head and escaped out a top relief port. Air was also supplied between the double walls to assure the conductive insulation of the helmet. The weight of the helmet assembly was counterbalanced and was not borne by the wearer.

The apparatus on which the subjects performed the choice reaction time and tracking tasks was fixed to a work station depicted in Figure 1. The work station was in two parts. One part consisted of a table on which were mounted the reaction time task display and control devices and the control stick for the tracking tasks. The table was used both inside the chamber during the trials and outside during training and preexposure data collection. The height of its surface was on the same plane as the arm of the subject's chair in the chamber. Apparatus with which a subject might come into physical contact was insulated to reduce heat transference to the subject or was made of material with low heat conductive properties. The other part of the work station consisted of the cathode ray tube (CRT) on which the tracking tasks were displayed. Above this was affixed the display that signalled the subject which task would be presented next.

Figure 1. Subject's Work Station Within the Chamber

During each trial, the subject was seated in a metal frame, nylon net chair located near the center of the chamber. The arms of the chair were padded with terry cloth. The position of the chair enabled ready observation of the subject from outside the chamber through an insulated glass window.

The tracking display apparatus for most of the training sessions and for the preexposure measurement differed from that of the tests. The final three training sessions were completed in the chamber using the work station. During the earlier training and during the preexposure measurements, the tracking task display was presented on a CRT setting on a mobile chart. The height of the CRT was such that the subject could readily view it over the top of the table-mounted apparatus.

The experimenter's control and monitoring equipment was located outside the chamber in an alcove placed to provide the experimenter a view of the subject through a viewing window. The apparatus included an analog computer, a CRT oscilloscope, two elapsed time counter displays with milli-second graduation, a control device for the reaction time task and task sequence signal display, and an electric clock. The analog computer was used in driving the tracking task signals and displaying subject performance to the experimenter. The experimenter's CRT was slaved to the subject's CRT and allowed the experimenter a view of the signal displayed to the subject. The elapsed time displays were connected to the experimenter's device, which controlled the subject's reaction time display. One timer indicated reaction time; the other indicated movement time. Each timer was reset after the values had been recorded. The reaction time control device also contained controls for the task sequence display signals located above the subject's CRT. The clock was used by the experimenter to determine the elapsed time since the subject entered the chamber so that tasks could be initiated pursuant to the protocol.

PERFORMANCE TASKS

The Mental Arithmetic Task was designed for nonverbal administration of a form known to be sensitive to changes in performance under the heat stressor being used. The task was a subject-paced, sequential addition and number comparison design The subject was required: (1) to note a left appearing one or two digit reference number; (2) to add an adjacent line of 12 single digit numbers sequentially from left to right until the sum equalled the reference number; and (3) strike a line through the last digit included in the sum with a marking pen. This procedure was repeated by the subject through the 3-minute task duration.The task formats were typed in characters 0.5 mm high with 0.5 mm separation between the bottom of one line and the top of the one below. They were mounted on cardboard for easier use by the subjects. Both accuracy and speed were encouraged. The subjects did not know the scoring rationale employed. Scores used as data were ratio scales of correct answers to the total number of problems attempted. Omitted lines before the last subject made entry were counted as having been attempted.

The Choice Reaction Time task was experimenter paced, stimulus controlled response, choice reaction time measurement of a 1:1 mapping of stimuli onto responses in a relatively unpracticed task. The subjects indicated readiness for the task by placing their right index finger on a central null position switch within a semicircular array of eight equidistant stimulus lamps and corresponding pushbutton response switches. The experimenter then illuminated two, four, or all eight lamps in a balanced array according to a predetermined sequence. The stimulus lamps remained illuminated for approximately 3 seconds, whereupon the experimenter extinguished one predetermined lamp. On observing one of the lamps extinguished, the subject removed his finger from the null switch and moved to depress the switch corresponding to the extinguished stimulus lamp. Depressing the correct switch extinguished the remainder of the stimulus lamps. If an incorrect switch was depressed, an error counter was tripped and the display remained illuminated until the correct choice had been made. When the correct choice had been made and all lamps extinguished, the subject returned his finger to the null switch to indicate his readiness to proceed with the next stimulus display.

When the experimenter activated a switch to extinguish a stimulus lamp, a millisecond timer was started. The timer ran until the subject removed his finger from the null switch, whereupon it was stopped. A second timer was started and ran until the subject struck one of the response switches.

Dependent variables recorded were the time which elapsed after the stimulus lamp was extinguished: (1) until the subject removed his finger from the null switch (reaction time), and (2) until the subject depressed a response switch (movement time). Response switches incorrectly selected were also recorded in the order in which selected.

Five sets of fifteen stimulus conditions, five for each bit combination, were presented for each trial. The approximate elapsed time from the start of the trial when each cycle began and ended was 2.5 minutes.

The choice of lamps to be illuminated and extinguished was predetermined on a quasi-random basis, thus each served as an equiprobable stimulus. Th order of presentation with respect to the two lamps (one bit), four lamps (two bits), and eight lamps (three bits) was also quasi-randomly determined. Table 1 shows the lamp arrangements.

TABLE 1
ILLUMINATED LAMP ARRANGEMENTS FOR REACTION TIME TASK

Information Content	Illuminated Lamp Arrangement
ONE BIT	1 8
	2 7
	3 6
	4 5
TWO BITS	1 2 7 8
	1 3 6 7
	3 4 5 6
	1 3 6 8
	1 4 5 8
	2 4 5 7
THREE BITS	ALL 8 LAMPS

Choice of the specific sequence to be used in each case was selected from the computer-prepared format. Sets of 15 arrangements containing five sets each of one, two and three bits displays were quasi-randomly prepared. Two limitations on randomness were placed on the selection: (1) ı o lamp arrangement was repeated consecutively; and (2) the lamp to be extinguished was not consecutively repeated, regardless of the previous lamp combination used.

The tracking tasks used were a modification of servo-theory based tasks developed by Jex et al. (1966a, 1966b, 1966c). Kelly (1969) described such a position compensation task as the simplest tracking proficiency measurement technique to have been derived from and related to describing function studies of the operator.

The tasks required the subject to retain a diverging signal within view on a CRT. The signal was displayed on a 4-inch diameter CRT placed 50 cm from and on a line with the subject's eyes. Subject control for the signal was through a rigid force-stick controller. The tasks were single-axis, closed-loop divergent systems where the divergent was constantly varied on a ramp input and were made inherently unstable by including positive error-rate feedback loops. The instability was initially small, increasing steadily during the course of the task performance. The point at which the subject's error exceeded the scale of the display was taken as the measurement of task performance. The position compensation tracking task compelled the subject to function as an amplifier providing gain. In the rate compensation task, he was constrained to operate as both an integrator and as an amplifier. The task forced the subject to generate neuromuscular lead dynamics with attendant higher risk of instability.

A Measurement Systems, Inc., Model 435 force-stick controller was selected to provide an isometric restraint for the limb controlling task, thereby minimizing neuromuscular lags which could confound the determination of the effective time constant (Jex et al., 1966b). Each form of the tracking task was performed in sets of four replications. Ten seconds elapsed between each replication. The position compensation tracking task was performed before the choice reaction time task, which was followed by the rate tracking task.

The dependent measure for each of the tracking tasks was an estimate of the subject's effective time constant. The value measured is an estimate of the subject's true neuromuscular reaction time delay, lag effects of mid-frequency neuromuscular dynamics, plus a nonlinear remnant (Jex et al., 1966b). The tasks were programmed on a Systron-Donner 10/20 Analog Computer. Table 2 contains the parameters of the task design.

TABLE 2
TRACKING TASKS PARAMETERS

	Position Task	Rate Task
Initial Value of Unstable Root	3.0 rad/sec	3.0 rad/sec
Lambda (λ) Rate	0.1 rad/sec	0.1 rad/sec^2
Control/Display Sensitivity	1.16 cm/N	1.16 cm/N
Display Viewing Gain for 50 cm Viewing Distance (visual angle/cm deflection)	1°7′	1°7′

The mechanization of the task apparatus departed from the Jex design in one essential feature. The Jex task involved presenting sequentially two rates of divergence input. The choice of two rates was selected to rapidly bring the subject to the proximity of critical instability, then allowed the operator to more slowly and precisely reach the critical point at which stability was lost (Jex et al., 1966b). The task used in this research employed a constant rate input rather than two sequential rates. The difference in task design was not such as to yield essentially different values. Using a single rate input of approximately the same value employed in this research, Frost (1969) found essentially the same means and standard deviations of scores as those reported for the dual input configuration. Moreover, Jex et al. (1966a) indicated the task parameters were not critical.

PROTOCOL

The effect of heat on performance, when detected, tends to be cumulative. Frequent repetition of short, demanding tasks was expected to detect changes in subject performance. Thus, the sequencing and time length available for each performance measure employed a common time line for all environmental conditions, even though the specific stimuli patterns presented to the subjects were preselected randomly. Each subject completed a pretest familiarization session outside the chamber. This consisted of two sets of each tracking task, two sets of reaction time tasks, and one mental arithmetic task, following the timing and sequencing of task presentations similar to that within the chamber.

Having completed these pretest performance tasks, the subject was prepared for entry into the chamber. He was weighed nude, the physiological monitoring sensors were attached, dressed in the clothing prescribed for the experiment, and weighed clothed. Thereafter, the physiological monitoring system was calibrated and a preexposure physiological baseline established. Shortly before the subject was introduced into the chamber he was required to void his bladder and then drink 600 cc of water to compensate for dehydration during the high temperature stressor conditions.

The time line and sequence of task presentations was the same in every test condition. The time line followed in the chamber appears as Table 3. The first task, a mental arithmetic task, began 5 minutes after the subject entered the chamber. The final task was concluded when the subject had been in the chamber 66 minutes. Another 2.5 to 3 minutes were required to remove the task equipment from in front of the subject, disconnect the electrical cable and air line leading to the subject's physiological monitoring sensors, remove the ventilating helmet (if used), and to help the subject from the chair and out of the chamber. The subject was then weighed, undressed, the sensors removed, and weighed nude.

TABLE 3
TEST TIME LINE

Elapsed Time (min)	Elapsed Time (sec)	Activity
1		Task equipment
	30	moved into place.
2		Instrumentation
	30	hooked up and
3		verified in work-
	30	ing order.
4		
	30	
5		
	30	
6		Mental
	30	Arithmetic
7		Task
	30	1st Set
8		
	30	
9		
	30	1st Order
10		Tracking
	30	Task
11		1st Set
	30	4 Replications
12		
	30	Choice
13		Reaction Time
	30	Task
14		1st Set
	30	15 Choices
15		
	30	
16		2nd Order
	30	Tracking
17		Task
	30	1st Set
18		4 Replications
	30	
19		1st Order
	30	Tracking
20		Task
	30	2nd Set
21		4 Replications
	30	
22		
	30	Choice
23		Reaction Time
	30	Task
24		2nd Set
	30	15 Choices
25		
	30	
26		2nd Order
	30	Tracking
27		Task
	30	2nd Set
28		4 Replications
	30	
29		
	30	
30		Mental
	30	Arithmetic
31		Task
	30	2nd Set
32		
	30	
33		
	30	
34		1st Order
	30	Tracking
35		Task
	30	3rd Set
36		4 Replications
	30	
37		Choice
	30	Reaction Time
38		Task
	30	3rd Set
39		15 Choices
	30	
40		
	30	2nd Order
41		Tracking
	30	Task
42		3rd Set
	30	4 Replications
43		
	30	
44		1st Order
	30	Tracking
45		Task
	30	4th Set
46		4 Replications
	30	
47		Choice
	30	Reaction Time
48		Task
	30	4th Set
49		15 Choices
	30	
50		
	30	2nd Order
51		Tracking
	30	Task
52		4th Set
	30	4 Replications
53		
	30	
54		1st Order
	30	Tracking
55		Task
	30	5th Set
56		4 Replications
	30	
57		Choice
	30	Reaction Time
58		Task
	30	5th Set
59		15 Choices
	30	
60		
	30	2nd Order
61		Tracking
	30	Task
62		5th Set
	30	4 Replications
63		
	30	
64		Mental
	30	Arithmetic
65		Task
	30	3rd Set
66		

Considerations affecting the scheduling for performance testing were influenced by the experimental design, facilities constraints, and factors over which the experimenter could exert no control. Morning tests were scheduled so that the subject entered the chamber at approximately 10:30 A.M. Afternoon tests were to begin at 2:30 P.M. Subjects reported approximately 90 minutes before scheduled tests to accomplish the preexposure task performance measurement, prepare for the test session, and calibrate the remote physiological monitoring equipment. Equipment malfunctions that caused a delay of more than 45 minutes from the scheduled starting times resulted in cancellation of the test for that day. Equipment malfunctions that occurred after the test was underway and were not corrected within 2 minutes caused the test to be terminated. If the subject of a terminated session could return within a week, he was scheduled for a different stressor condition, otherwise, he was rescheduled for the same stressor condition on his next appearance.

Subjects were scheduled so that their first test would be conducted in a benign environment and the alternate time of day benign test would be near the end of the tests. Comparing the performance in these two sessions would serve to identify a learning effect. Except for this constraint, the order of stressor conditions for a given subject was approximately random. For those subjects whose personal schedules permitted several sessions over a few days, none were exposed to two high temperature stressor sessions with less than 3 days elapsing between each session. When this occurred it was necessary to depart from randomness and schedule a remaining benign environmental condition subsequent to a high temperature condition. A greater constraint upon randomness across all subjects was imposed by equipment limitations, which required all sessions on a given day to be under the same temperature condition.

Three subjects did not complete all research conditions. One of the eight conditions was missed by each. No condition was missed by more than one subject. Subject 2 missed the afternoon high temperature ventilated session due to his withdrawal from further heat stress exposure on medical grounds. Subjects 1 and 5 missed the morning and afternoon benign ventilated sessions, respectively. Conflicting military duties prevented these subjects from completing the series within the period of time the chamber was available for this research. The data obtained for the other condition for each of these subjects and the alternate conditions across all subjects provided some basis for estimating missing values. Missing values determined were based upon assumptions derived from inspecting the data.

Mental Arithmetic Accuracy was the ratio of the number of additions attempted to the number completed correctly. Considerable subject variation was observed in the number of additions attempted. In preparing the missing values data for this task, the experimenter prepared an estimate of each subject's number of additions attempted and number completed correctly. For the preexposure period, the pair of values estimated was the mean of that subject's values in the other seven conditions. For the three observations within the chamber, the values estimated were that subject's deviation from the mean of the other subjects' values in the alternate time condition, added to the mean of the other subjects' scores in the cell having the missing values. This method took into account possible variation due to the experimental condition involved. While less conservative than the preexposed estimates, the experimenter considered it a better estimate of what the subject's performance would have been had he completed the tests.

REACTION TIME, MOVEMENT TIME, AND TRACKING SCORES

The three subjects having missing values were those whose performance appeared to approximate the mean value in those cells where all subjects completed the protocol. Consequently, the estimated values for these variables were the mean values of the other five subjects at the respective points in the protocol. These mean values were replicated the appropriate number of times to complete the cell entries. Although not elegant, I believed it provided both a conservative and reasonable estimate.

REACTION TIME AND MOVEMENT TIME RESPONSE ERRORS

The reaction time task apparatus provided for stimulus controlled response by the subject. Direct mapping of response switches to stimulus lamps was done to minimize the probability of erroneous responses on the part of the subjects. Erroneous response to reaction time tasks frequently approach 2-3% of total responses (Pachella, 1974). The number of errors experienced in this research were far less than the typically observed.

TABLE 4
SUMMARY OF RESPONSE ERRORS

	Preexposure	Exposure
Reaction Time		
Number	3.0	11.0
% of Total	.21	.31
Movement Time		
Number	29.0	4.0
% of Total	2.01	.11

The greatest incidence of errors was found during the preexposure familiarization periods. The three errors observed in the reaction time component involved responding to an inappropriate response switch. No subject made more than one error of this type. The 29 movement time errors involved undershooting or overshooting the switch or failure to depress it sufficiently to cause its activation.

The 11 reaction time errors observed during the exposure conditions were widely distributed across time blocks. No subject made more than one error in a single time block. Seven of the 11 errors were made by subject 6; these were distributed as two errors to one bit, two errors to two bits, and three errors to three bits.

Because of the low appearance of errors, no analysis of error propagation was performed. Time measurements associated with erroneous responses were not included in the data. Instead, artificial values were employed which represented the mean value of the other responses in the time block where the error occurred for that bit level for that subject. Deletion of erroneous response times is commonly employed in dealing with erroneous responses although such an approach has been criticized (Pachella, 1974). None of the Pachella (1974) suggested error treatment methods was attempted because of the relatively limited occurrence of errors. The only measure for which one of these methods would have been practical was the preexposure movement time. However, in veiw of the limited purpose intended by recording preexposure measures, the experimenter did not elect to peform any of the suggested analyses.

RESULTS AND DISCUSSION

This research employed measures of subject performance on four tasks repeated in cycles throughout each test condition. The independent variable of principal interest was the effect of thermal stressor insult on performance of each task. The performance measures were designed to be independent of each other and their results have been so considered.

Several of the analysis of variance (ANOVA) summary tables herein were extracted from complete summary tables. The full summary tables were reported in Courtright (1976). Where simple effects were determined, they have been included in the ANOVA summary tables.

THE MENTAL ARITHMETIC TASK

Pretest familiarization mental arithmetic task accuracy scores showed significant differences only between the subjects. Thus, no diurnal, training, or anxiety factors were in evidence.

The three task replications completed within the environmental chamber were tested for significant within subjects differences in performance due to four effects. These were (1) whether the tests had been conducted in the morning or afternoon, called a diurnal effect; (2) the elapsed time after entering the chamber; (3) the temperature in the chamber, called a heat effect; and (4) whether the subjects' heads were ventilated during the exposure. Figure 2 depicts the mean performance in the benign and heat stress conditions at the three time periods when the tasks were performed. An extract of the significant findings follows in Table 5.

One within subjects effect was found significant at the 10% level. That was the interaction of the temperature within the chamber and the elapsed time after entering when the tasks were accomplished. Two significant simple effects were found for the interaction. A further test of the Time effect under the high temperature conditions was made using the Newman-Keuls procedure. These tests indicated that the mean accuracy performance at the end of the high temperature tests differed significantly both from that at the beginning ($p < .05$) and from that at the midpoint ($p < 10$). Accuracy in the

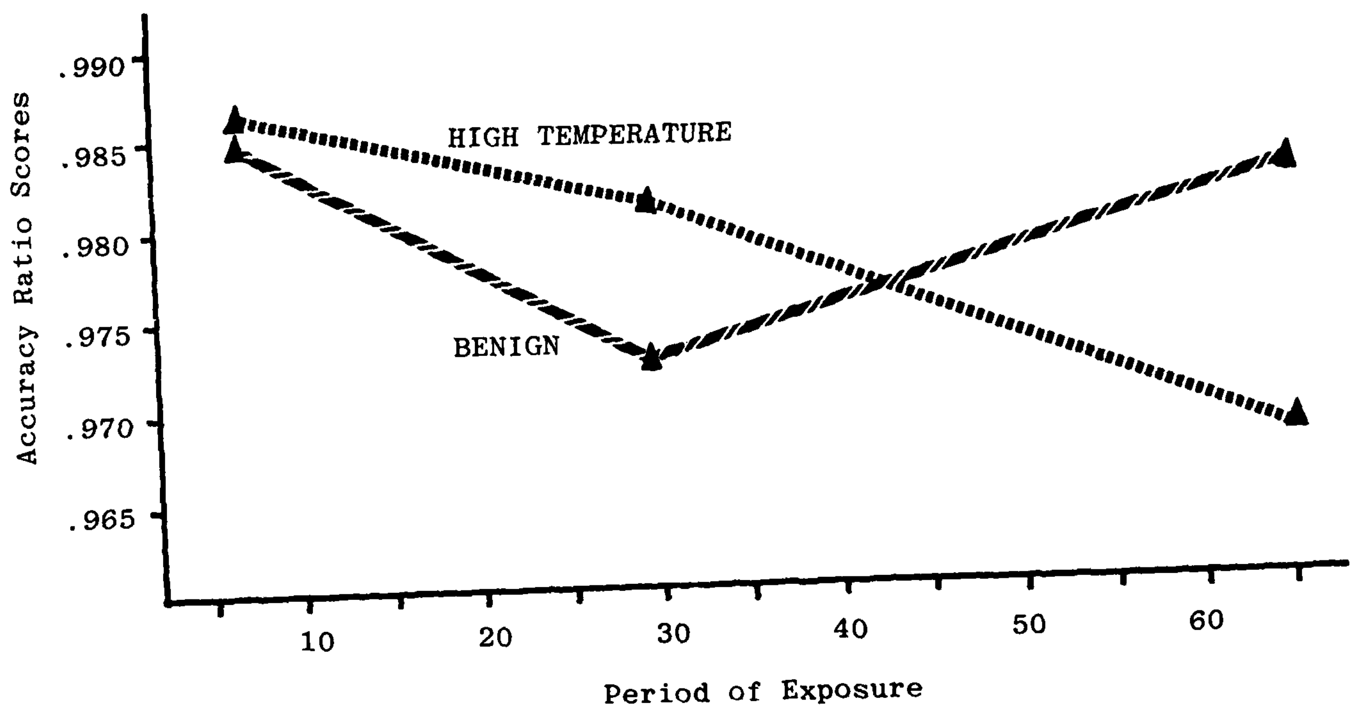

Figure 2. Mean Mental Arithmetic Accuracy Profiles by Heat Level

closing minutes of the stress and stress ventilated tests was significantly poorer than that in the closing minutes in the benign and benign ventilated tests. In addition, the accuracy in the closing minutes of exposure in the stress and stress ventilated conditions was significantly poorer than accuracy earlier under these conditions.

Performance under the exposure conditions was consistent with earlier studies having similar stress levels. Performance decline appeared after the thermal insult had had an opportunity to build up. Tolerance for this level of heat was good for at least 30 minutes. The nature of the task was such that it imposed a load on short-term memory (Kahneman, 1973). This capacity was apparently affected by thermal stressor after a period of time.

TABLE 5
EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR MENTAL ARITHMETIC ACCURACY DURING EXPOSURE

Source of Variance	df	MS	F	p
Between Subjects	1	138.10014	26080.152	$<.0001$
Error	5			
Within Subjects	138			
. . . . . .				
H (Heat)	1	.00006	<1	ns
Error	5	.00087		
H at T_1	1	.00002	<1	ns
H at T_2	1	.00087	1.5777	ns
H at T_3	1	.00227	4.142	$<.10$
Error	15	.00055		
. . . . . .				
T (Time)	2	.00145	1.534	ns
Error	10	.00095		
T at H_1	2	.00104	1.558	ns
T at H_2	2	.00196	2.932	$<.10$
Error	20	.00067		
. . . . . .				
H x T	2	.00155	3.968	$<.10$
Error	10	.00039		

Mean rectal temperature changes at the time when significant differences were noted were 0.32°C in the stress with head ventilation tests and 0.70°C in the stress tests. Poulton (1970) suggested that increased arousal, such as might result from the effects of the thermal stressor, tends to increase speed but reduce accuracy. The subjects showed little change in the mean number of problems attempted in the unstressed tests. However, in the two stress conditions, more problems were attempted at the midpoint than at either the beginning or end of the tests. Thus, the observed midpoint "speed-up" did not hold as the subjects approached the limits of their tolerance to the insult. As in the Blockley and Lyman study (1950), several of the subjects reported difficulty in concentrating on the final task in the stress tests. The concentration difficulty manifested itself in an accuracy penalty only as the number of problems attempted in the closing minutes of the stress tests was approximately the same as in the beginning.

In the Kissen et al. (1974) study significant changes were not observed despite core temperature elevations approaching 0.80°C during the final task performance. Kissen et al., employed a thermal stressor in which the temperature was lower and the humidity level higher. The Kissen et al. task used four single-digit numbers processed to involve addition, multiplication, and decision making about whether the solution was an odd or even number. Analyses were made of the mean number of successful solutions during each time block. No data were presented on the relative accuracy of the performance. The major implication for comparison of the Kissen et al. findings with those of this study concerns core temperature changes. Kissen et al. employed moderate stressor, which despite the longer exposure period may have been less stimulating than that used in this research. Moreover, differences in the character of the tasks in the two studies made inferences between the two highly speculative.

Provins (1966) proposed that body core temperature was related to subject arousal level in hyperthermic studies. He later concluded there was no simple index that could be used, but rather that it probably involved changes in the relationship between body and skin temperatures (Provins et al., 1974). These findings, when taken with similar studies, tend to reject Provins earlier contention. Performance of these subjects deteriorated with a relatively small change in body core temperature, but earlier work by Fox et al. (1963; Wilkinson et al., 1964) and by Colquhoun and Goldman (1972) found performance to be unchanged or slightly enhanced at the same core temperature levels; decrement was found when temperature was elevated by approximately 1.5°C. In the Blockley and Lyman study (1950), rectal temperature at the midpoint of the tests was raised 0.38°C and no impairment was found; however, their performance metric was based only on correct scores. The "speed-up" in total problems attempted, found in this study, paralleled their finding.

Apparently, the elevation of body temperature through the method of controlled hyperthermia, such as employed by Fox et al. (1963), differs in its impact on performance from that resulting from elevation of the core temperature through the effects of a hostile thermal environment. This implies that temperature elevation alone is insufficient to account for the performance differences. However, tasks involving short-term recall and which are arousing by their very nature, do seem to be fairly intolerant of relatively slight elevations of body temperature. Precisely where the threshold of change occurs has not been established by results reported to date. If the change is a result of some combination of changes in the relationship of skin and core temperatures and the nature of the thermal insult, as has been suggested by Provins et al. (1974), the nature of that relationship has yet to be established. In this study, examination of indices of heat stored per square meter of body surface area and changes in weighted body temperature, which considers both skin and core temperature, failed to provide a clear indication of the relationship. Only time passage in the thermal environment, with corresponding elevation of rectal temperature, showed a relationship to the performance decrement.

THE CHOICE REACTION TIME TASK

Two dependent variables were measured each time a subject responded to a change in the task display. The first was the length of time the subject required to perceive a change in the stimulus state and begin a response by removing his finger from the null switch—reaction time. The second was the period of time required for the subject to complete his movement to a response switch and depress that switch—movement time.

REACTION TIME COMPONENT

Seven sets of measures of the reaction time component were taken from each subject during each test. Two sets were made during the pretest familiarization. The remaining five task sets were completed within the environmental chamber.

PREEXPOSURE REACTION TIME

Each of the two sets consisted of five measurements for each of the three levels of stimulus information content, the independent variable. These data were subjected to an ANOVA with repeated measurements on each factor and subject. The within subjects factors were (1) a diurnal effect; (2) the subjects' knowledge of the stressor to be employed in the test to follow, called a conditions effect; (3) the information content of the stimulus, called a bits effect; and (4) whether the measurements were made in the first set or the second set of responses, called a time effect.

One treatment effect was significant at the 1% level; that was the difference in reaction time due to the information content of the stimuli. When further evaluated using the Newman-Keuls procedure, the differences between each of the three levels was significant at the 5% level. This relationship between information content based on the number of choices available in the task and choice reaction time was shown in 1952 by Hick and has been repeated many times since (Welford, 1968). When subjected to a least regression analysis, the slope of the choice reaction time responses was found to be 11.38 milliseconds per bit; the intercept was approximately 288 milliseconds.

The task did not require any warm-up; subject responses did not differ significantly between the two sets of task stimuli. No evidence was shown that competence improved with the added practice on the task. Knowledge of the environmental stressor in the ensuing exposure tests did not affect performance significantly. Some indication of a difference was evident in morning and afternoon test performance. This possibility was suggested by the Diurnal main effect, which was significant at the 10% level, and by two interactions involving diurnal influence, both also significant at the 10% level. Although the 10% level was not considered sufficient to merit post hoc analysis, particularly since no diurnal influence was found in analysis of exposure tests, the finding of the potential for some diurnal influence merits comment.

Responses in the afternoon were slightly faster than those in the morning. In the afternoon, mean rectal temperature was approximately 0.34°C greater than the mean morning temperature. Kleitman et al. (1938) observed an inverse relationship between choice reaction time and rectal temperature due to diurnal variation, observing changes for temperature differences as little as 0.28°C. Their study also showed choice reaction time in the afternoon to be better than that in the morning. In 1966, Provins suggested changes in arousal level were related to differences in body core temperatures. He suggested that elevation of the body temperature increases arousal level while lowering of the temperature has a corresponding effect of lowering arousal level. The results of the preexposure analysis of choice reaction time provide some support to that position.

REACTION TIME DURING EXPOSURE

The five task sets of responses completed in the chamber consisted of five measures for each of the three levels of stimulus information content. These data were subjected to an ANOVA with repeated measures on each factor. The within subjects factors were (1) a diurnal effect; (2) the environmental heat stressor level; (3) whether or not the subject's head was ventilated; (4) the information content of the stimulus, a bits effect; and (5) the time which had elapsed since entering the environmental chamber.

Significant differences were found on three within subjects main effects, on two 2-factor interactions, and on three 3-factor interactions. These are depicted in extract form in Table 6. For complete summary tables and post hoc analyses, see Courtright (1976). The only design factor not having some significant influence was the diurnal factor. Post hoc simple effects for the significant interaction terms were determined. To ease interpretation of the findings, discussion follows in terms of the main factors of the experimental design: heat, ventilation, information content, and time after entering the chamber.

TABLE 6
EXTRACT OF ANALYSIS OF VARIANCE SUMMARY FOR RT DURING EXPOSURE

Source	p
Between Subjects	$< .001$
Within Subjects	
Heat	$< .05$
Bits	$< .001$
Heat x Bits	$< .05$
Time	$< .05$
Heat x Time	$< .05$
Heat x Ventilation x Time	$< .05$
Heat x Bits x Time	$< .005$
Ventilation x Bits x Time	$< .005$

The effect of heat on reaction time was confounded by information content and exposure time. Table 7 indicates where significant differences in response times occurred related to information content and time after onset of the thermal stressor. Response times were generally shorter in the presence of the temperature stressor. This facilitative effect was greatest for the single bit stimuli. This was seen first after the subjects had been in the chamber 37 minutes; it was apparently sustained through the fourth set of responses and was also apparent during the final measurement period. The facilitating effect on reaction to the two bits stimuli was less pronounced, but appeared earlier. Simple simple main effects at T_1 suggest an early onset, but this was not sustained at T_2. The facilitative effect was clearly evident at T_3 and subsequently. When stimulus information content was increased to three bits, the facilitating influence appeared only during T_3. However, this influence was reversed over the subsequent 20 minutes. No significant difference was noted at T_4; the heat stressor markedly slowed the T_5 response times. These findings suggest the heat stressor exhibits a cumulative effect onto higher information content stimuli. The facilitative effect was ineffectual for exposures of up to approximately 30 minutes. The heat tended to improve performance over the ensuing 9-10 minutes. However, sustained facilitation for the next 20 minutes was found only where stimulus information content was low. When the stimulus had three bits of information, the phenomenon was seen to be reversed and response to these more complex stimuli slowed in the presence of the heat stressor.

TABLE 7
SIGNIFICANT DIFFERENCES ATTRIBUTABLE TO HEAT STRESSOR LEVEL

Test Measurement Period	Stimulus Information Contact		
	One Bit	Two Bits	Three Bits
1 (12 min 30 sec - 15 min)	ns	$<.10$	ns
2 (22 min 30 sec - 25 min)	ns	ns	ns
3 (37 min - 39 min 30 sec)	$<.05$	$<.05$	$<.005$
4 (47 min - 49 min 30 sec)	$<.10$	$<.10$	ns
5 (57 min - 59 min 30 sec)	$<.005$	$<.10$	$<.001$

In 1966 Provins suggested that in studies of heat stress, the arousal level of the subjects involved could be implied from changes in core temperature of the body. The differences observed in choice reaction time responses under heat stress were also considered using this concept of differing arousal levels. When significant differences in responses to stimuli having one bit of information content appeared, the body core temperature under heat was at or above normal, and the mean difference in rectal temperature was greater than approximately 0.4°C. No significant differences were observed during the first two task measurement periods. During these periods, the mean core temperatures were slightly lower than the preexposure level. Therefore, at both of those times, the subjects were somewhat under-aroused as indicated by their body temperature. However, responses under heat were significantly faster at T_3. There the mean core temperature evaluation above preexposure levels was 0.1°C for the heat stress tests. Mean temperature differences for benign environment tests −0.34°C. During the subsequent two measurement periods, mean reaction time responses continued to be faster in the heat. The body temperature continued to rise under the heat stressor; in the benign environments, it declined further below the mean preexposure level. By the final measurement period, the difference in core temperature between the stress and benign environments was approximately 0.84°C.

As with responses to one bit stimuli, when significant differences in responses to stimuli having two bits of information were observed, mean body core temperature differences were approximately 0.4°C. As with responses to one bit stimuli, this appeared when the mean body temperature level measured during the heat tests was at or higher than the preexposure level. However, responses to two bits stimuli were also faster under the heat than in the benign environments during the initial time measurement (significant at the 10% level) when core temperatures measured in both environments were below the preexposure level. The difference was approximately 0.15°C. During the second time period, when no significant differences were noted, the mean body temperatures measured under both environmental conditions were 0.24°C less than preexposure levels. Responses to two bits stimuli, therefore, suggested that core temperature was not a valid index to predict reaction time changes due to differences in arousal level when the body temperature is slightly depressed.

Differences in responses to three bits stimuli were not significant until T_3, approximately 38 minutes after entering the chamber. At T_3 the mean core temperature of the subjects in heat stress was slightly above the preexposure normal body temperature level, while in the benign environment it was 0.34°C below the preexposure level. The T_3 responses were faster in the heat environment (significant at the 5% level). At Time 4, approximately 48 minutes, the mean body temperature under heat was elevated 0.22°C above preexposure level and the benign mean body temperature level was 0.38°C below the preexposure level. At this point the over-aroused state of the subjects may have reached a point where the arousal level began to interfere with rather than facilitate responses, since no differences were noted between performance in the heat and benign environments. During T_5 (approximately 58 minutes), performance in the heat was considerably slower than in the benign environments. By this time the core temperature was 0.42°C above preexposure level.

These observations suggested that as the information content of the stimuli increased, the increasing effect of over-arousal tended to interfere with response speed. Where the information content was low (i.e., one bit or two bits), elevation in core temperature above normal by some factor approaching 0.4°C tended to consistently improve response times through the range of core temperature differences observed in this study. However, when the stimulus information content was increased to three bits, the impact on performance of being in an over-aroused state differed. Initially it had a facilitating effect. But as the subjects continued to be more aroused by the thermal environment, as indicated by body temperature differences of greater than 0.6°C, the facilitating effect gave way to a relative loss in performance effectiveness as indicated by a slowing of responses.

These observations with respect to stimuli having one bit and two bits of information in its content are reasonably consistent with the findings of Kleitman et al. (1938). He saw reaction time performance improvements when body temperature differences due to diurnal effects alone exceeded 0.28°C. The work of Fraser and Jackson (1955) on serial reaction time supports the observations with respect to three bits stimuli. They created an over-arousal effect through both the imposition of a heat stressor and through the presentation of continuous stimuli to the subject with an irregular requirement to respond. In that study reaction time responses lengthened over time.

In Bursill's (1958) study, the impact on reaction time performance in heat was apparent when the subjects were task loaded by simultaneously having to perform both reaction time tasks and tracking using the Pursuitmeter. When Bursill varied the difficulty of the tracking tasks, thereby varying the information processing load, reaction time to higher information loads was slower than it was to lower information loads. The Bursill study was essentially replicated in 1972 by Azer et al. The general implication for higher information content was also suggested by the findings of Grether et al. (1971). They evaluated choice reaction time response measures obtained while the subjects were required to perform simultaneously on a compensatory tracking task, thus compelling the subjects to process a greater information load than that contained in the reaction task alone.

Benor and Shvartz (1971) found no significant differences in responses to forewarned simple reaction time stimuli despite pronounced body temperature increases. In that study, core temperature was elevated approximately 2°C by exercise in a hyperthermic environment. The task involved was a simple one, requiring response to the appearance of an alarm light. Their performance measures included reaction and movement time. The subjects were required to reach to extinguish an alarm lamp while walking on a treadmill. Although not reported, a considerable response variability to this task seems likely, since mean differences in excess of 4% were not found to be significant. Thus, although Benor and Shvartz did not find response differences to low information content stimuli to be related to body temperature change, the nature of their response variable was appreciably different from those used in this study and the other referenced.

The main effect for ventilation was not significant. However, two interactions involving ventilation were significant: Heat x Ventilation x Time at the 5% level, and Ventilation x Bits x Time at the 0.5% level. Significant simple effects derived from these interactions appear in Table 8.

TABLE 8
SIGNIFICANT SIMPLE EFFECTS

Ventilation x Bits x Time Interaction		Heat x Ventilation x Time Interaction	
Effect	p	Effect	p
V x B at T_4	< .10	V at HT_{13}	< .05
V x B at T_5	< .001	H x V at T_5	< .005
V x T at B_3	< .001	V at HT_{15}	< .05
V at BT_{15}	< .01	V at HT_{25}	< .05
V at BT_{31}	< .05	V x T at $_2$	< .05
V at BT_{32}	< .05	H at VT_{15}	< .01
V at BT_{35}	< .005	V at VT_{23}	< .01
		H at VT_{25}	< .001
		V at HT_{22}	< .05
		V at HT_{25}	< .01
		H x T at V_1	< .01

Ventilating the head in the benign heat condition significantly ($p < .05$) slowed reaction time at T_3 and T_5 over the corresponding unventilated condition. It also slowed it significantly over the corresponding points when performance occurred in the presence of the heat stressor. Ventilating the head without the presence of the heat stress insult apparently placed some burden on the subjects which affected their responses to the middle and endpoint tasks of the test periods. This could not be readily attributed to differences in arousal level as indicated by mean rectal temperature. At each of the task performance times, the rectal temperatures observed under head ventilation in the benign environment were lower than in the unventilated condition. Moreover, the difference between the two was very nearly the same for all time periods. Thus, arousal level as indicated by rectal temperature did not offer a ready explanation for the observed responses although a threshold point cannot be ruled out.

Ventilating the head in the presence of the heat stressor tended to stabilize reaction time performance as to bring the mean response times in line with corresponding unventilated benign performance. The heat stressor caused a marked deterioration of performance at T_2 (approximately 24 minutes) and at T_5 (approximately 58 minutes) in the unventilated condition. This effect was counteracted by bathing the head with cool air. Differences in arousal level may have accounted for the improvement noted at T_5. In the unprotected environments, the elevation of core temperature was approximately 0.65°C whereas in the stress ventilated condition it was approximaty 0.28°C. This 0.37°C difference suggests that the subjects were much more highly aroused in the stress condition than in the stress ventilated. However, that cannot be said for the differences observed at T_2 when the mean rectal temperatures differed by a mere 0.11°C. A difference in core temperature greater than 0.11°C was noted at T_3 and T_4, where no significant differences in response times were observed. Thus, consideration of arousal level as indicated solely by body core temperature does not offer a consistent indication that it was the cause of observed performance differences in the heat as compared to the heat ventilated states.

The second interaction involving ventilation was the Ventilation x Bits x Time intereaction, which was significant at the 0.5% level. Significant simple effects related to the interaction were presented in Table 8.

The appearance of the significant simple interaction effects for V x B at T_4 ($p < .10$) and V x B at T_5 ($p < .001$) indicated the expected positive regression effect was altered as a result of head ventilation. Responses to one bit stimuli at T_5 in the unventilated state was significantly faster ($p < .01$) than in the ventilated state. Responses to the three bits stimuli showed the reverse effect and was significant at the 0.5% level. In the presence of the aiding effect of ventilation of the head, the stabilizing effect noted in the discussion of heat effects seemed to hold. Ventilation had the effect of ameliorating deterioration over time; however, an initial penalty was paid as seen in the significantly longer response time to three bits stimuli under ventilation during the initial measurement periods. This was indicated by the simple effects of V at BT_{31} and BT_{32}, both significant at the 5% level.

Ventilation appeared to exert a different effect on low information stimuli than it did on high information content stimuli. Under ventilation, the response times to the one bit stimuli were progressively longer over the exposure period. At T_5 this difference was significant at the 1% level. This was not so when the head was unventilated. Responses to the two bits stimuli did not differ over time or ventilation condition. Responses to the three bits stimuli were differently affected. In the unventilated state, response times showed an increase over the exposure period, being particularly long at T_2 and T_5. At these times, response was slower in the unventilated tests at the 5% and 0.5% levels, respectively. When the head was ventilated, response times generally did not differ significantly over the times of measurement, although response at T_1 to three bits stimuli was significantly slower ($p < .01$) than in the unventilated tests.

The impact of ventilation on differential information content responses implied an arousal level influence at work. When the head was ventilated in the high temperature environment, bits regression slopes at each task time were quite similar to those in the benign environment. In fact, there was less variance about the slope in the heat-ventilated condition than was observed using the benign condition data. Thus the relationship originally shown by Hick, and frequently repeated since, was seen in these two conditions.

With one exception, the regression slope values for each task time period under heat stress were greater than those in the heat ventilated condition. Slope values appear in Figures 3 through 6. The exception was the initial task performance. Thus, the cool air ventilating the head in the hostile environment enabled the subjects to process the higher information content more quickly than when the head was not cooled. This was particularly true for the three bits stimuli. Responses to three bits stimuli were appreciably longer during the final task period in heat stress. Body core temperature differences between these two conditions were approximately 0.35°C by then. Core temperatures were elevated in both conditions. Under heat stress they approached 0.65°C. Thus, the subjects were over-aroused in the heat stress. So much so that the arousal interfered with their ability to process the greater information load. They were also aroused in the heat ventilated condition, but the level of arousal slightly enhanced information processing rather than interfered with it.

Half of the significant within subjects effects involved stimulus information content. The bits main effect and all simple main effects involving bits showed significant differences in reaction time to the stimulus information levels. However, several of the simple simple main effects involving bits revealed circumstances wherein pronounced reaction time differences in information content were not found.

In the benign trials, passage of time after the midpoint of the exposure appeared to lessen the expected differences between bits levels. Mean response times and significance levels observed are indicated in Table 9. Reference to Figures 3 and 4 provides insight into this. In the unventilated, unstressed trials, response patterns show the expected positive slope regression phenomena. Figure 4 shows this was not so when the head was ventilated. In that condition, no clear positive slope regression effect appeared after the third measurement point. In the presence of the high temperature heat stressor significant differences were noted at all measurement times, affirming the expected positive slope regression.

TABLE 9
MEAN RT FOR H x B x T INTERACTION

	Benign Heat H_1				High Temperature Heat H_2			
	Stimulus Info. Content			Sig.	Stimulus Info. Content			Sig.
Time Block	B_1	B_2	B_3	Level p	B_1	B_2	B_3	Level p
T_1	321	344	357	< .05	309	325	354	< .005
T_2	328	348	390	< .001	320	356	389	< .001
T_3	336	360	397	< .001	325	338	368	< .001
T_4	342	358	371	< .10	325	341	374	< .001
T_5	355	357	364	ns	324	339	415	< .001
Sig. Level p	< .10	ns	< .01		ns	ns	< .001	

In the task performed at 36 minutes 30 seconds-39 minutes in the benign environment, responses to three bits stimuli were the longest of the five task sets in that condition. In the two subsequent tasks, responses to three bits stimuli were approximately the same as in the two task sets completed before 36 minutes. However, mean responses to the one bit and two bits stimuli were appreciably slower than observed in the first three task sets. They were also the slowest found for any time period under any condition. Moreover, the changes in responses to all bits levels during these two final time periods resulted in pronounced regression slope changes. The slopes for T_4 and T_5 in the benign ventilated condition were 3.3 ms/bit and -8.1 ms/bit, respectively.

At T_3 the subjects' mean rectal temperature was approximately 0.4°C below the preexposure mean. At T_4 it was approximately 0.46°C below the preexposure. At T_5 it had further dropped to approximately 0.48°C below preexposure.

Responses to three bits stimuli required the greatest information to be processed. Under-arousal experienced at -0.4°C was sufficient to affect response performance, but it did not do so at -0.46°C or -0.48°C. Responses to one bit and two bits stimuli were not affected at -0.4°C but were adversely affected at -0.46°C and -0.48°C. This suggested that responses to three bits stimuli were the first to be affected by the falling arousal level. This conclusion was consistent with Kahneman's (1973) comments that the range of optimal arousal level narrows as the task complexity increases. However, the nature of the three bits task was in itself more arousing than one bit and two bits tasks, since its information processing load was heaviest. When task sets at T_4 and T_5 were presented, the self-arousing nature of the more complex task was apparently sufficient to overcome the under-arousing influence of the core temperature decline. For the simpler stimuli this was so.

At T_5 this position was supported by the observation that responses to one bit stimuli were longest while responses to three bits stimuli were shortest. This general implication was further supported by the polynominal regression analysis of the reaction time slope values. Both the linear and quadratic regressions of slope values were negative. The quadratic regression was most definitive in depicting the change in information processing concurrent with the steady decline in mean body core temperature.

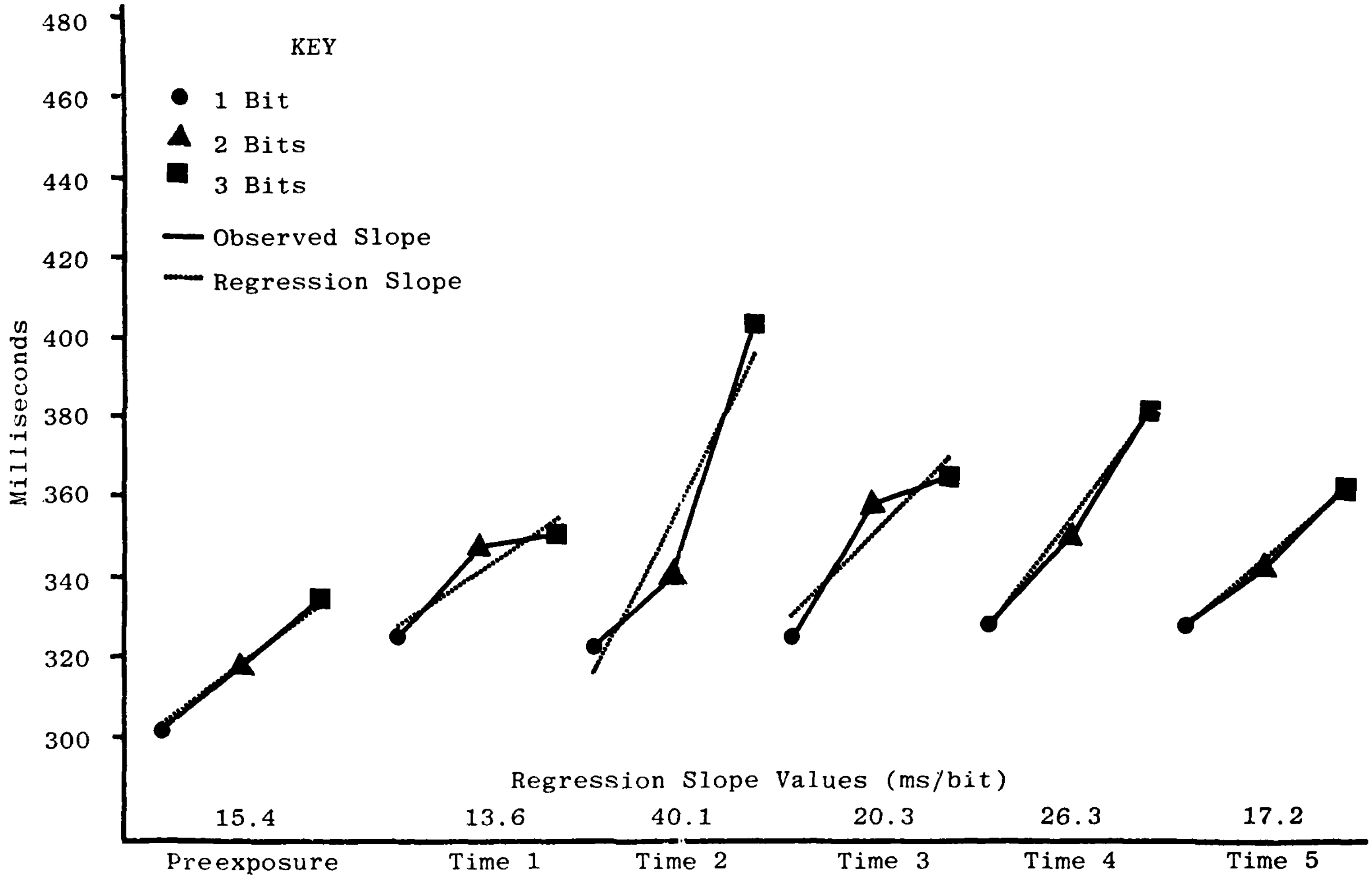

Figure 3. Reaction Time in Benign Condition

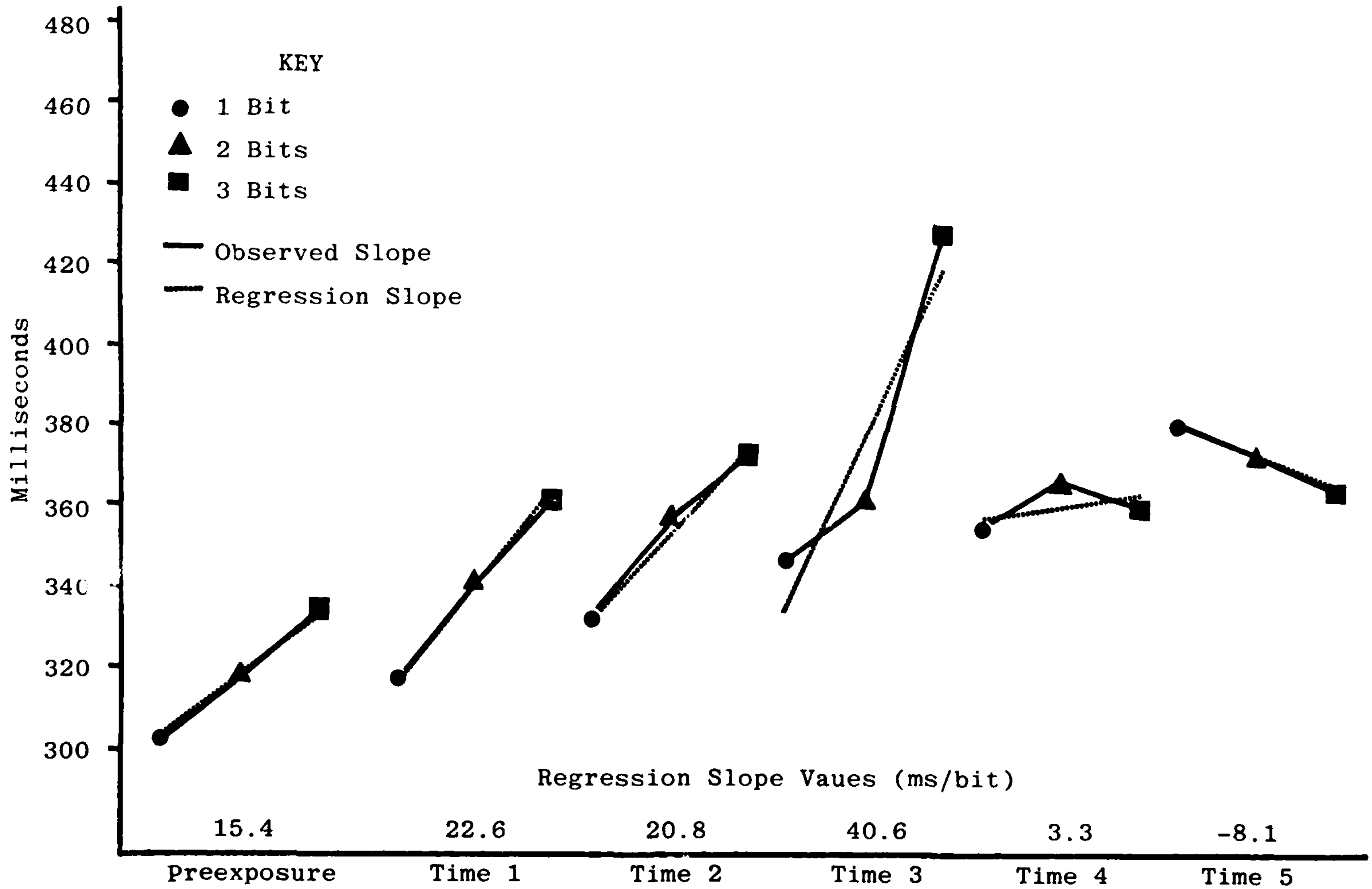

Figure 4. Reaction Time in Benign Ventilated Condition

Three simple simple main effects for bits at the two ventilation states and over time failed to indicate significant differences. Bits simple simple effects involving ventilation appear at Table 10. Reference to Figures 3 and 5 suggests the reason for the nonsignificant finding for B at VT_{11}. The 3-point regression line for the two heat stressor conditions shows slopes in excess of 13 ms per bit for both. These differed little from the preexposure comparison slope of 15 + ms per bit. However, these figures reveal that response to the two bits stimuli took nearly as long as response to the three bits stimuli. This appears to account for failure of significant differences to appear.

TABLE 10
BITS SIMPLE SIMPLE EFFECTS INVOLVING VENTILATION

Effect	p	Effect	p
B at VT_{11}	ns	B at VT_{21}	< .001
B at VT_{12}	< .001	B at VT_{22}	< .001
B at VT_{13}	< .001	B at VT_{23}	< .001
B at VT_{14}	< .001	B at VT_{24}	ns
B at VT_{15}	< .001	B at VT_{25}	ns

Rectal temperatures at that time point do not indicate this to have been due to arousal level differences. Although under-arousal might have been a contributing influence, the same phenomenon was not found in the heat ventilated condition when the mean rectal temperature was quite similar.

Five of the eight significant Within Subjects effects revealed by ANOVA involved the passage of time. The Time main effect was significant at the 5% level, suggesting some overall fatigue or boredom influence on performance. This overall effect was influenced strongly by specific test conditions.

Mean response times for the Heat x Ventilation x Time interaction, which was significant at the 5% level, are given in Figure 7. Significant differences at the 1% level due to time passage were observed when the head was ventilated in the benign condition. When the high temperature stressor was used without ventilation, differences were significant at the 0.1% level. No differences were found in the alternate conditions of benign temperatures without ventilation and where the head was ventilated and a high temperature stressor was employed.

An erratic response pattern emerged in the hyperthermic tests when the head was not ventilated. Responses at T_1 were quicker than the other three conditions. Responses at T_2 were appreciably slowed and were the longest observed. Some recovery of response quickness was noted at T_3 and T_4, mean response times being quicker than at comparable points in the benign condition, which serves as a "normal" reference comparison. At T_5 the mean response was considerably slowed. Figure 5 revealed this slowing to be largely attributable to a pronounced slowing of responses to three bits stimuli. The overall pattern suggests the thermal insult manifests an impact between 15 and 22 minutes after onset of the stressor. Thereafter the subjects apparently can compensate well for the stressor through T_4. After 56 minutes of cumulative stressor approximately 48 minutes after onset of exposure. In addition, considerable variation in information processing performance, represented by regression slope values, appeared at approximately 33 minutes after the start of these tests, suggesting an earlier impact on information processing.

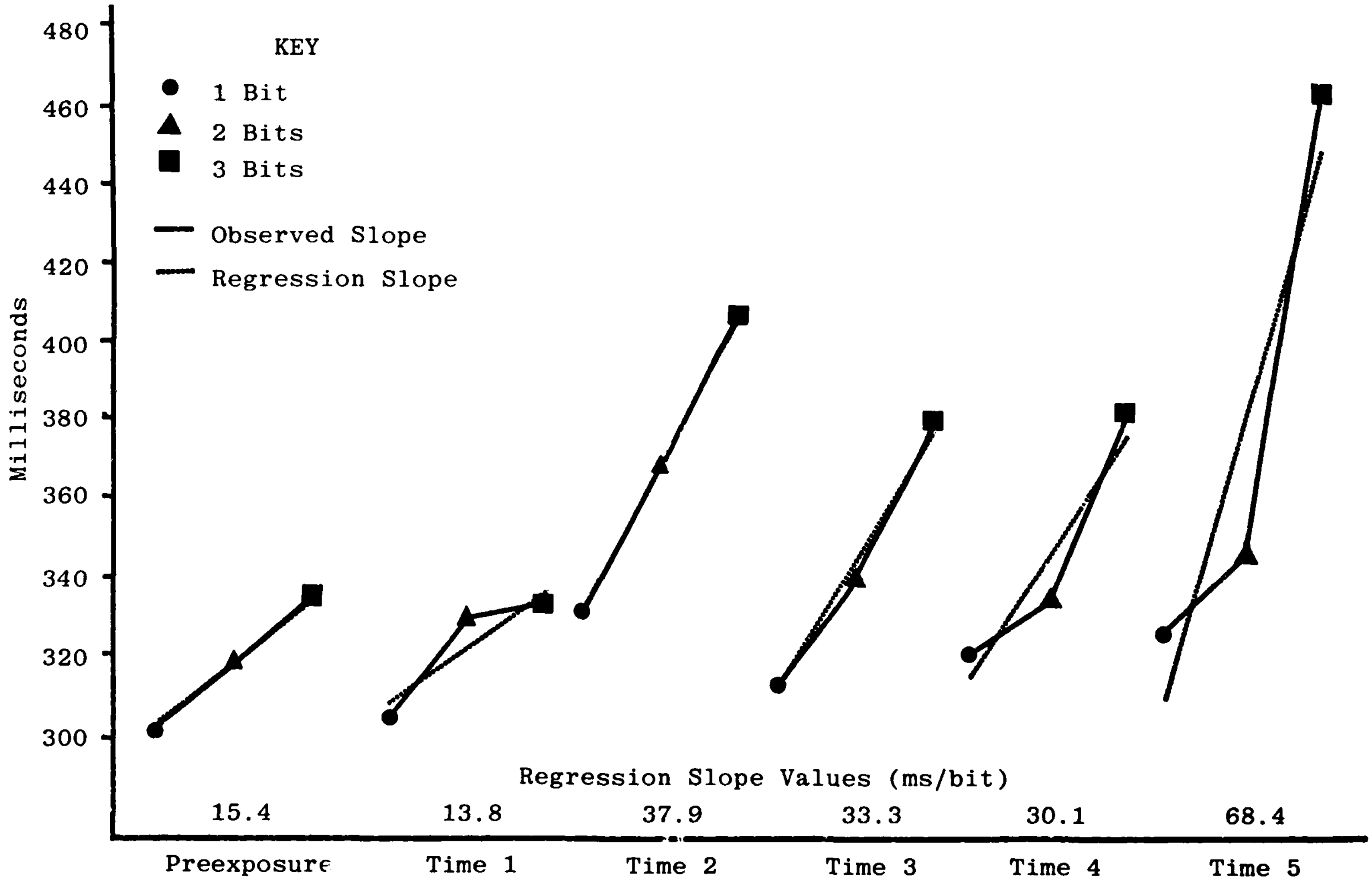

Figure 5. Reaction Time in Heat Stress Condition

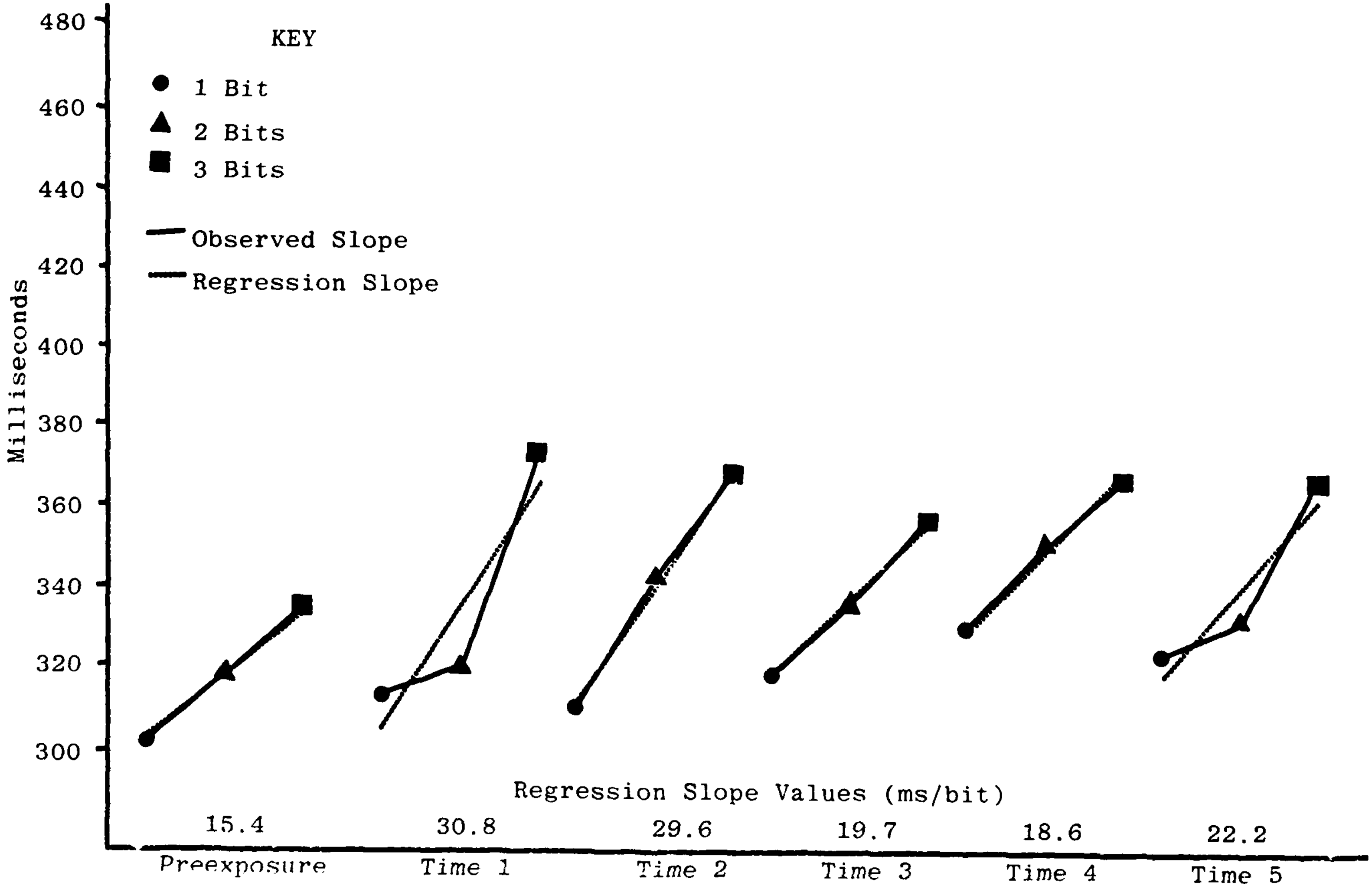

Figure 6. Reaction Time in Heat Ventilated Condition

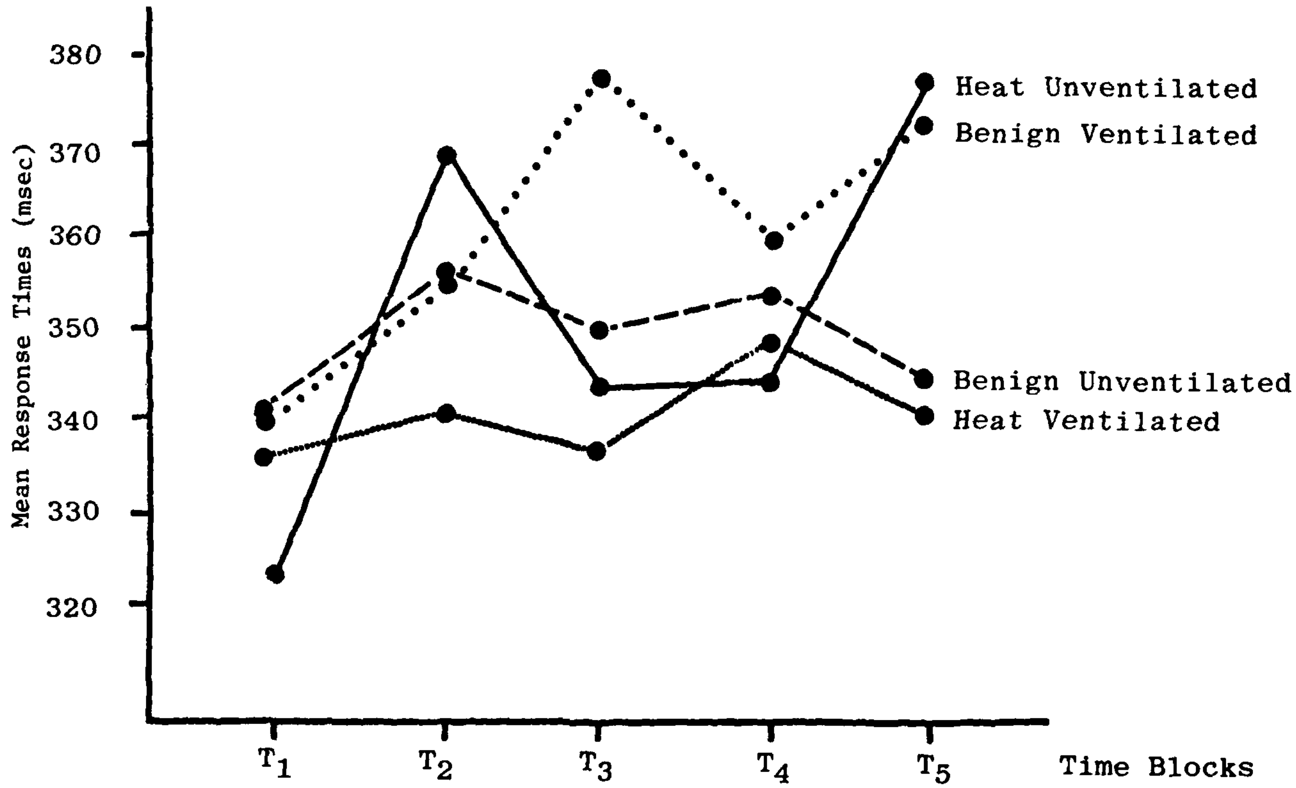

Figure 7. Heat x Time x Ventilation Interaction

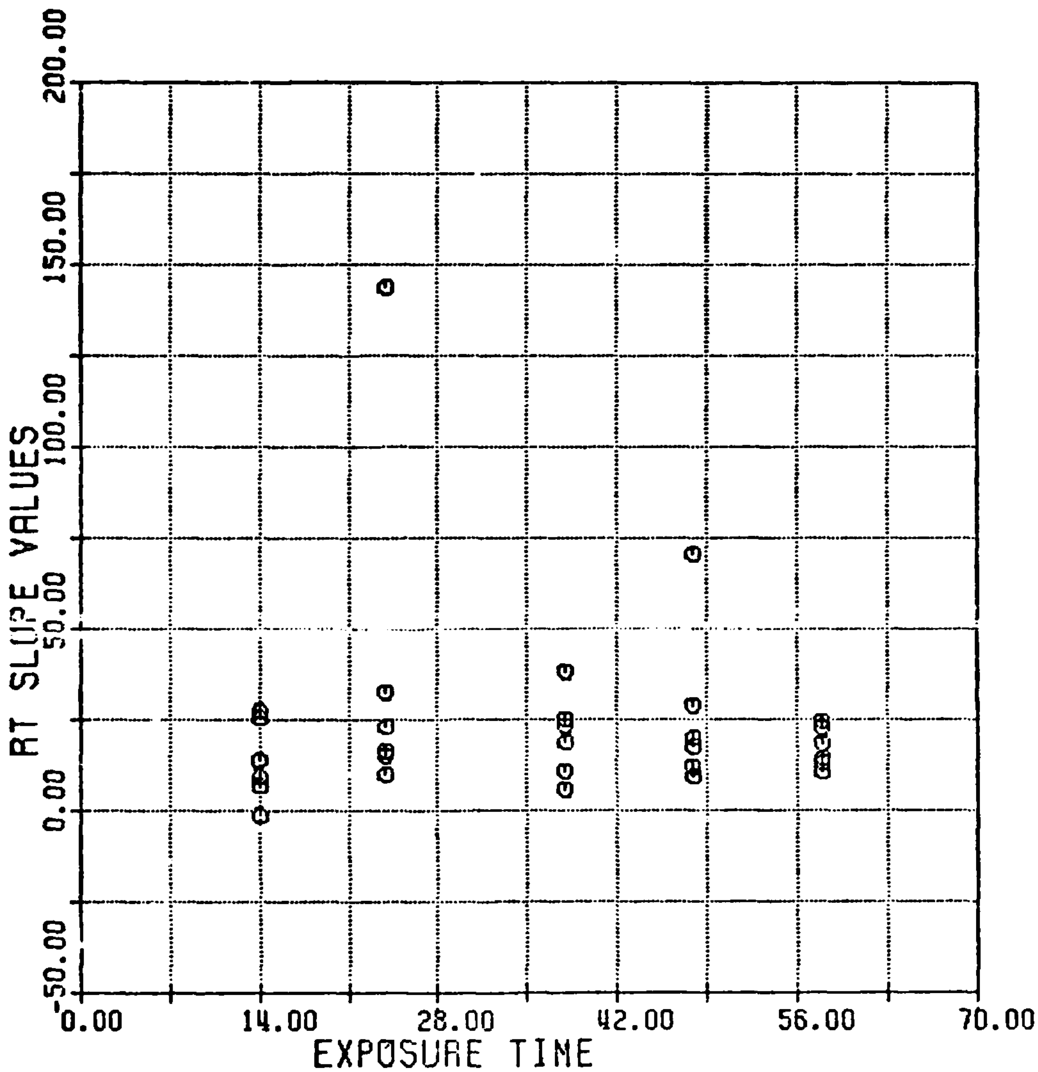

Figure 8. Benign Condition Reaction Time Slopes

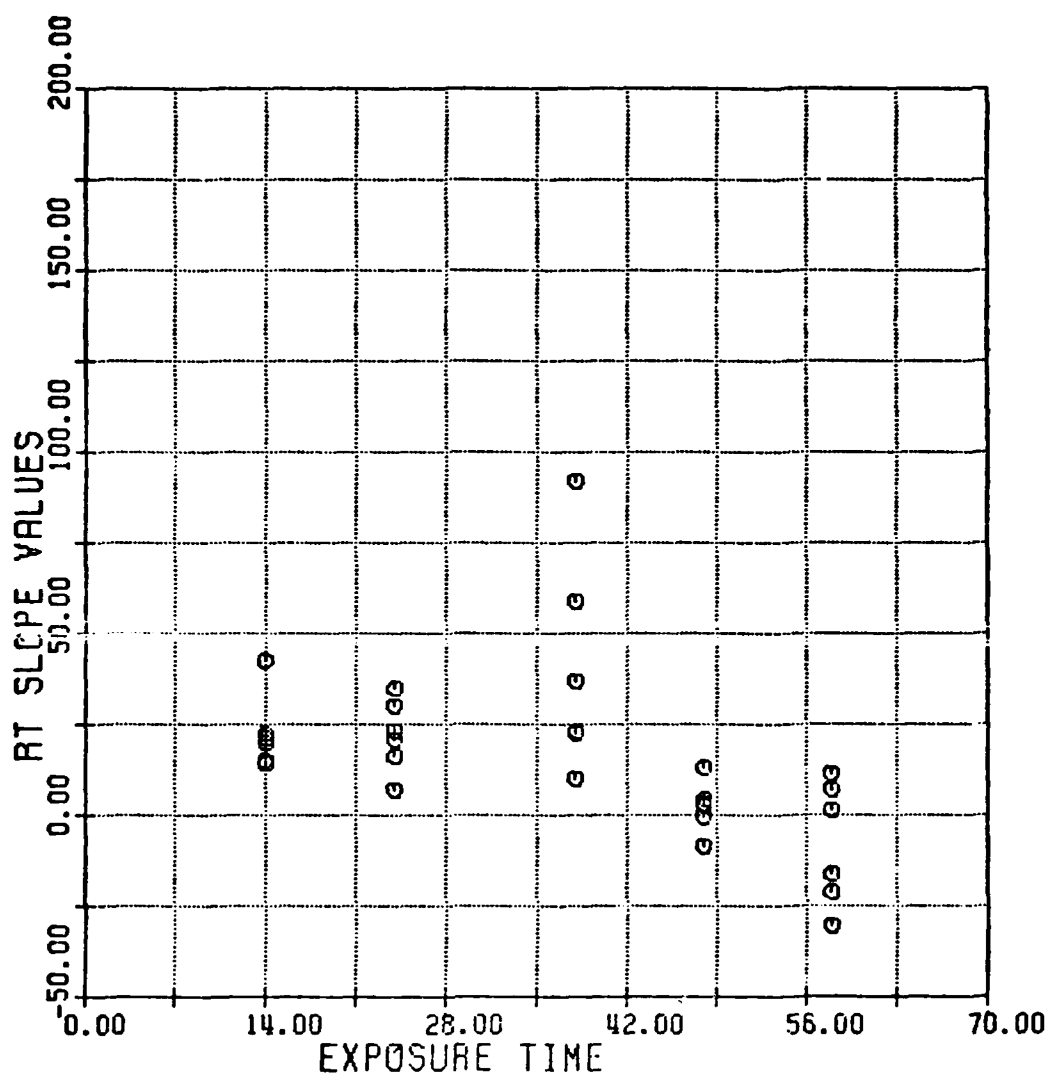

Figure 9. Benign Ventilated Reaction Time Slopes

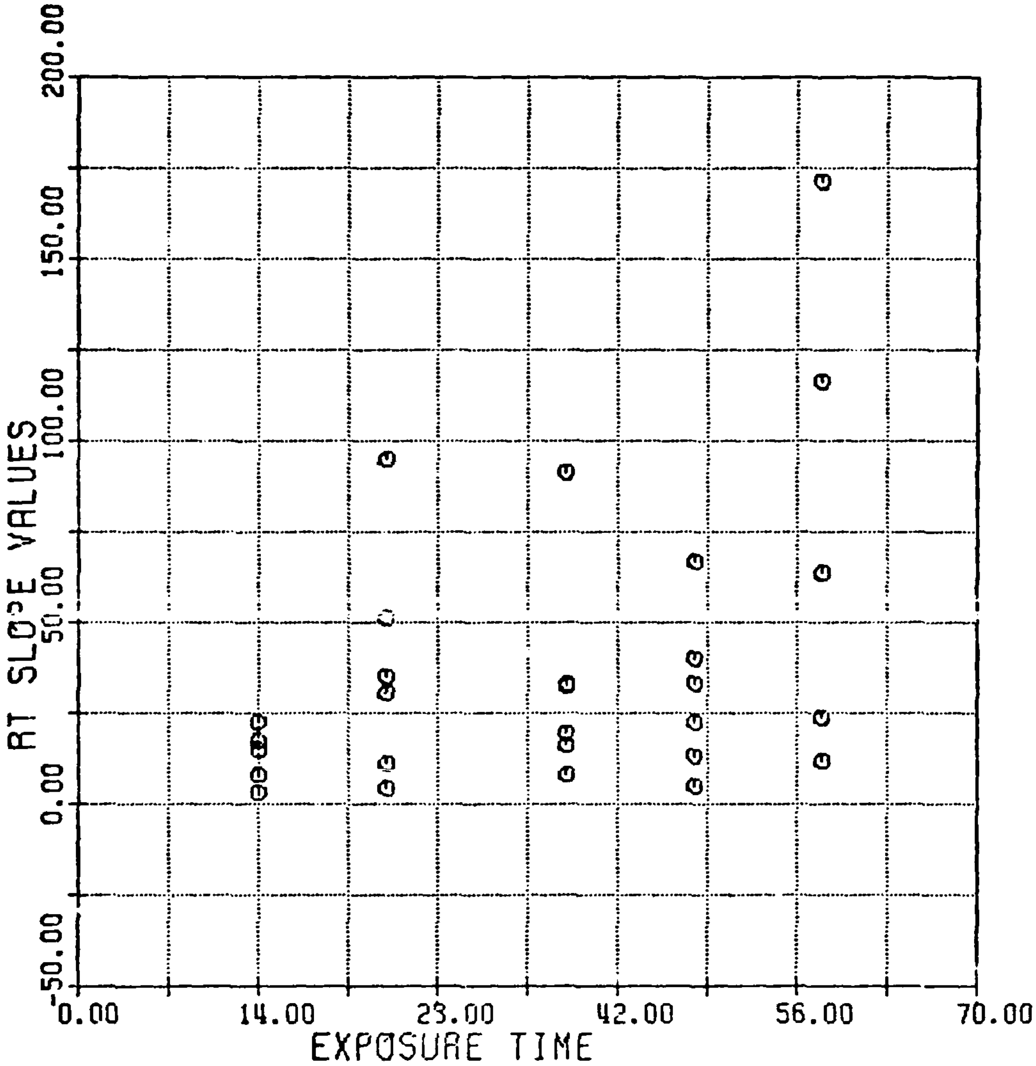

Figure 10. Heat Stress Condition Reaction Time Slopes

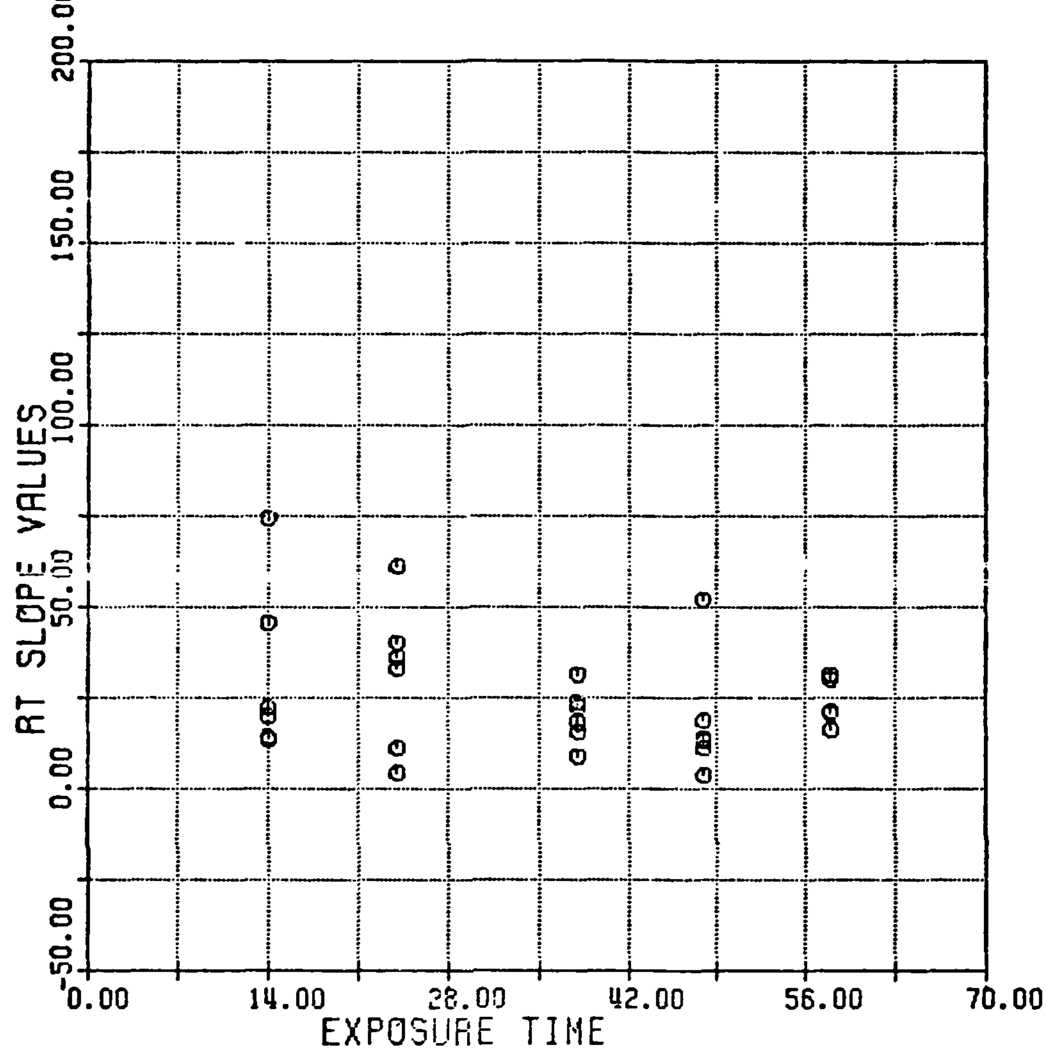

Figure 11. Heat Ventilated Condition Reaction Time Slopes

TABLE 11
EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR REACTION TIME SLOPES DURING EXPOSURE

Source of Variance	df	MS	F	p
Between Subjects	1	76317.750	44.315	< .001
Error	5	1722.151		
Within Subjects	114			
C (Conditions)	3	223.745	3.622	< .05
Error	15	613.889		
C at T_1	3	446.132	< 1	ns
C at T_2	3	397.478	< 1	ns
C at T_3	3	619.172	1.166	ns
C at T_4	3	910.281	1.714	ns
C at T_5	3	6091.597	11.469	< .01
Error	75	531.116		
T (Time)	4	750.611	< 1	ns
Error	20	783.308		
T at C_1	4	649.501	1.122	ns
T at C_2	4	2179.017	3.766	< .01
T at C_3	4	2376.117	4.106	< .01
T at C_4	4	226.664	< 1	ns
Error	80	578.664		
C x T	12	1560.227	3.057	< .10
Error	60	510.423		

The high temperature stress condition polynomial regressions were significant for linear regression at the 5% level and for cubic regression at the 10% level. Figure 13 depicts the three regression lines determined. Figure 13 confirms the limited character of the quadratic regression, which was not significant, and suggests the best fit is provided by the cubic regression. The cubic regression depicts both the significant impact arising from accumulated insult of the thermal stressor during the final time period and an earlier insult that appeared during the second time block. Although this earlier change was not statistically signifcant, it suggested an early thermal insult impact on subject performance that did not show further effects until shortly before termination of the exposure. This affect was also clearly depicted in Figure 5.

MOVEMENT TIME COMPONENT

For each reaction time component of the choice reaction time task there was a corresponding movement time component. Seven sets of movement time measurements were made for each subject under each condition. Two sets were made during the pretest familiarization. The other five were recorded for the subjects' responses within the chamber.

PREEXPOSURE MOVEMENT TIME

Preexposure reaction time tests were conducted 45-60 minutes before the exposure tests. They were made in an ambient temperature of approximately 75°F. Four factors could have had a systematic influence on the movement time component of the choice reaction time task. These factors were (1) diurnal; (2) the information content level of the stimuli; (3) knowledge of the thermal stressor in the test to follow; and (4) a time factor, since there were two sets of the task presented with each preexposure test. There was also a potential for change in movement time performance that results from skill improvement as the task was further practiced over the course of the experiment.

No treatment effect was found to exert a systematic influence on observed movement time. However, one three-way interaction term was found to be significant at the 5% level. That interaction involved Conditions (i.e., knowledge of the stressor level to follow), Bits (i.e., the information level of the stimuli), and Time (i.e., first set versus second set of measurements). Mean values for that interaction are depicted in Figure 14. Figure 14 failed to suggest any consistent relationship. Evaluation of simple effects for the interaction also failed to reveal consistent general effects. Instead, various simple main, simple interaction, and simple simple effects revealed statistical significance.

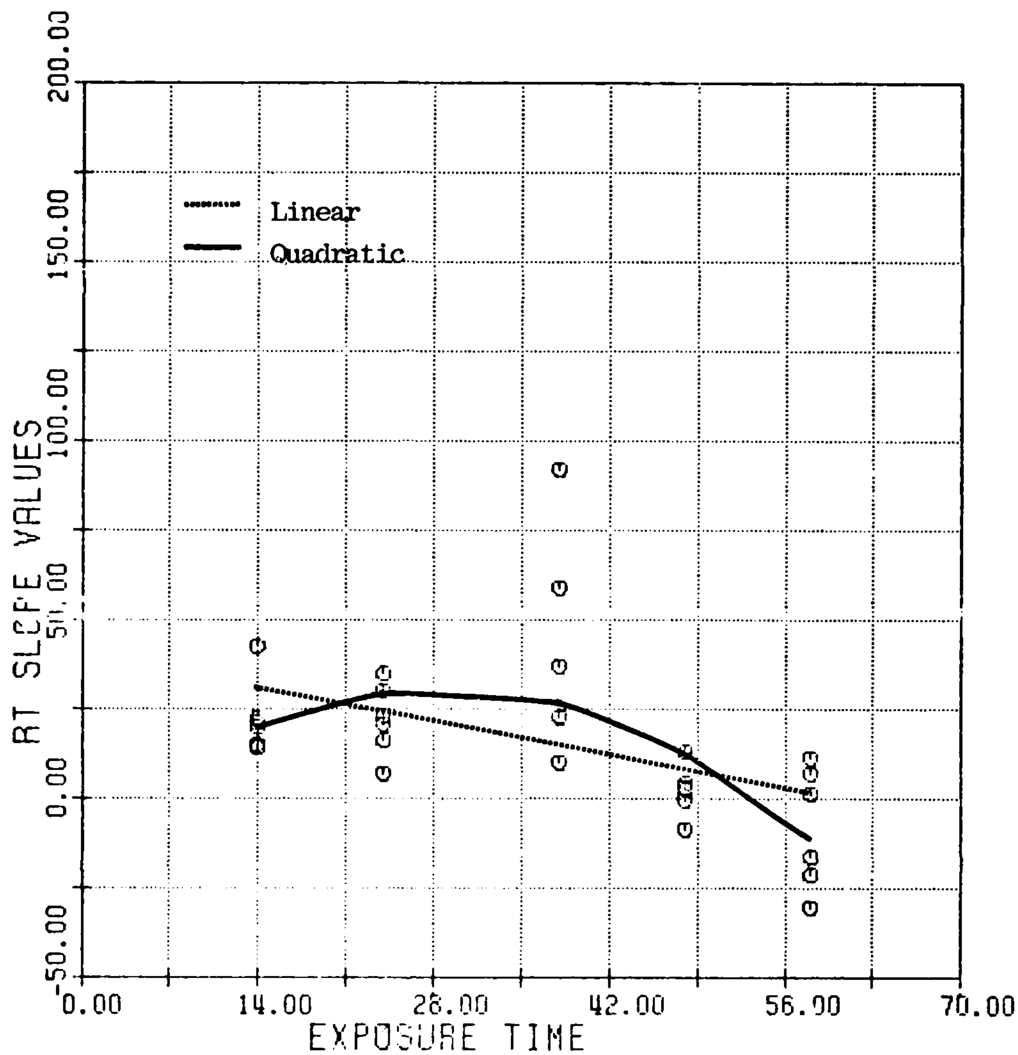

Figure 12. Polynomial Regressions of Reaction Time Slope Changes in the Benign Ventilated Condition

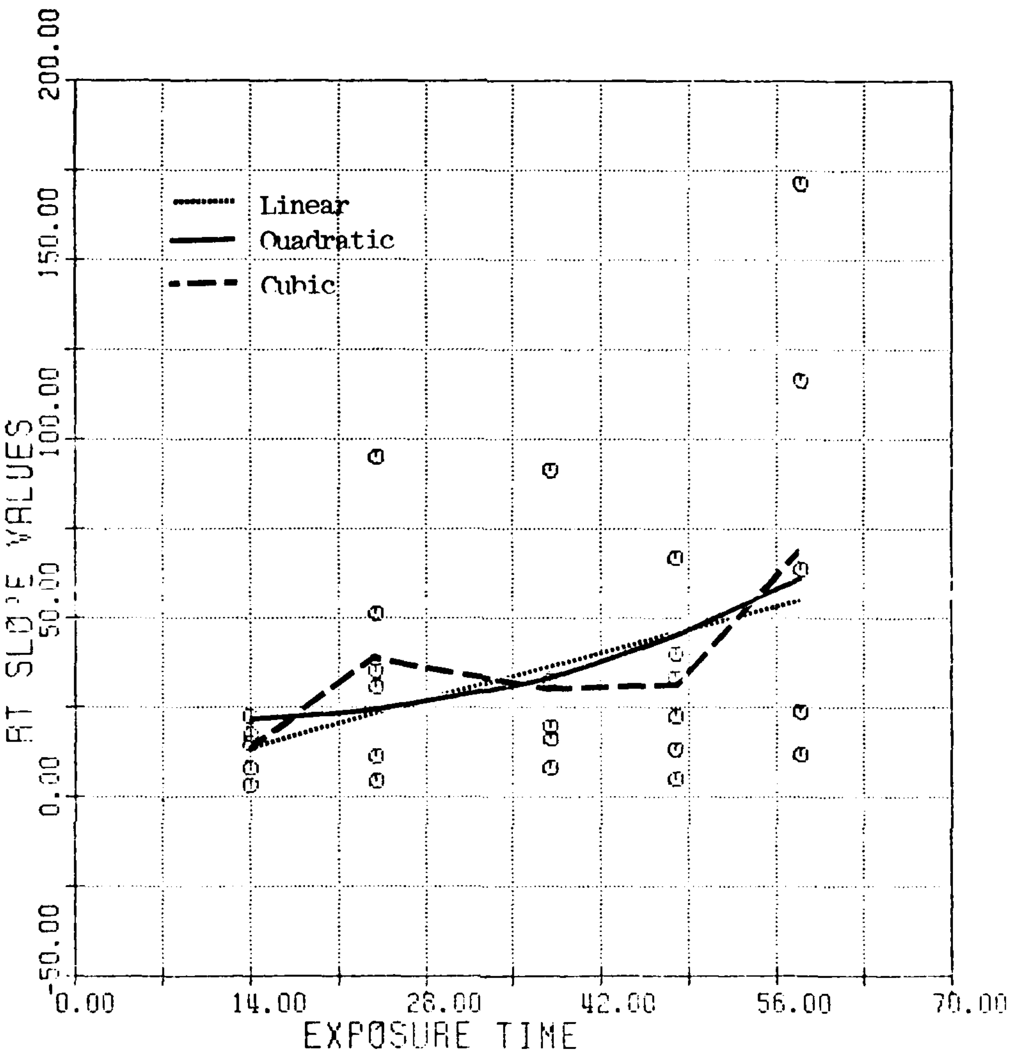

Figure 13. Polynomial Regressions Time Slope Changes in the Heat Sress Condition

Evaluation of these simple effects suggested two general conclusions that may be advanced somewhat tenuously. The first was that responses to two bit stimuli was somewhat faster during the second set of tasks. This was suggested by the simple main effect T at B_1 and by the simple simple main effect T at CB_{41}, both significant at the 10% level. The second was that responses to two and three bits of stimuli showed greater variability than did responses to one bit stimuli. Responses during the first set of tasks were faster than during the second set for one bit and three bits stimuli. However, only the one bit responses were consistently faster as indicated by the 10% level of significance found for the simple effect T and B_1. Despite a mean difference in excess of 11 milliseconds for three bits stimuli movement responses, this difference was not significant because of the variability in response behavior.

In general, four conclusions were drawn from evaluation of preexposure responses. First, some improvement in movement time response was achieved through reaquaintance with the task itself, as indicated by improvement in response times during the second set of tasks. This was more noticeable and consistent for responses to one bit stimuli. Second, no consistent differences in movement time were found to be a function of the information content of the stimuli; an observation previously noted by Welford (1968). Third, there was considerable variation in movement response time that defied attempts to relate this variation systematically to the variables under consideration in this research. Finally, there was no indication that movement time improved with greater practice on the task. Hence, there was no indication of a learning effect. This latter conclusion arises as a result of failure to find a significant Diurnal x Condition interaction.

MOVEMENT TIME DURING EXPOSURE

Measures of the movement time component of the choice reaction time task during the exposure tests were subjected to analysis for five treatment effects. These were (1) diurnal; (2) environmental heat level; (3) head ventilation; (4) the passage of time during the tests; and (5) the information level of the stimuli.

TABLE 12

EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR MOVEMENT FOR TIME DURING EXPOSURE

Source of Variance	df	MS	F	p
Between Subjects	5	1.86045	103.416	< .001
Error	2880	.01799		
Within Subjects	714			
D (Diurnal)	1	.01904	< 1	ns
Error	5	.05495		
D at H_1	1	.08862	2.690	ns
D at H_2	1	.01052	< 1	ns
Error	10	.32939		
H (Heat)	1	.00002	< 1	ns
Error	5	.05341		
H at D_1	1	.03884	1.210	ns
H at D_2	1	.04120	1.281	ns
Error	10	.03217		
H at V_1	1	.09431	2.973	ns
H at V_2	1	.09084	2.864	ns
Error	10	.03172		
D x H	1	.08011	7.329	< .05
Error	5	.01093		
V (Ventilation)	1	.77357	9.747	< .05
Error	5	.07936		
V at H_1	1	.10092	2.258	ns
V at H_2	1	.85778	19.192	< .005
Error	10	.03172		
H x V	1	.18513	18.462	< .005
Error	5	.01003		
B (Bits)	2	.07209	4.574	< .05
Error	10	.01576		

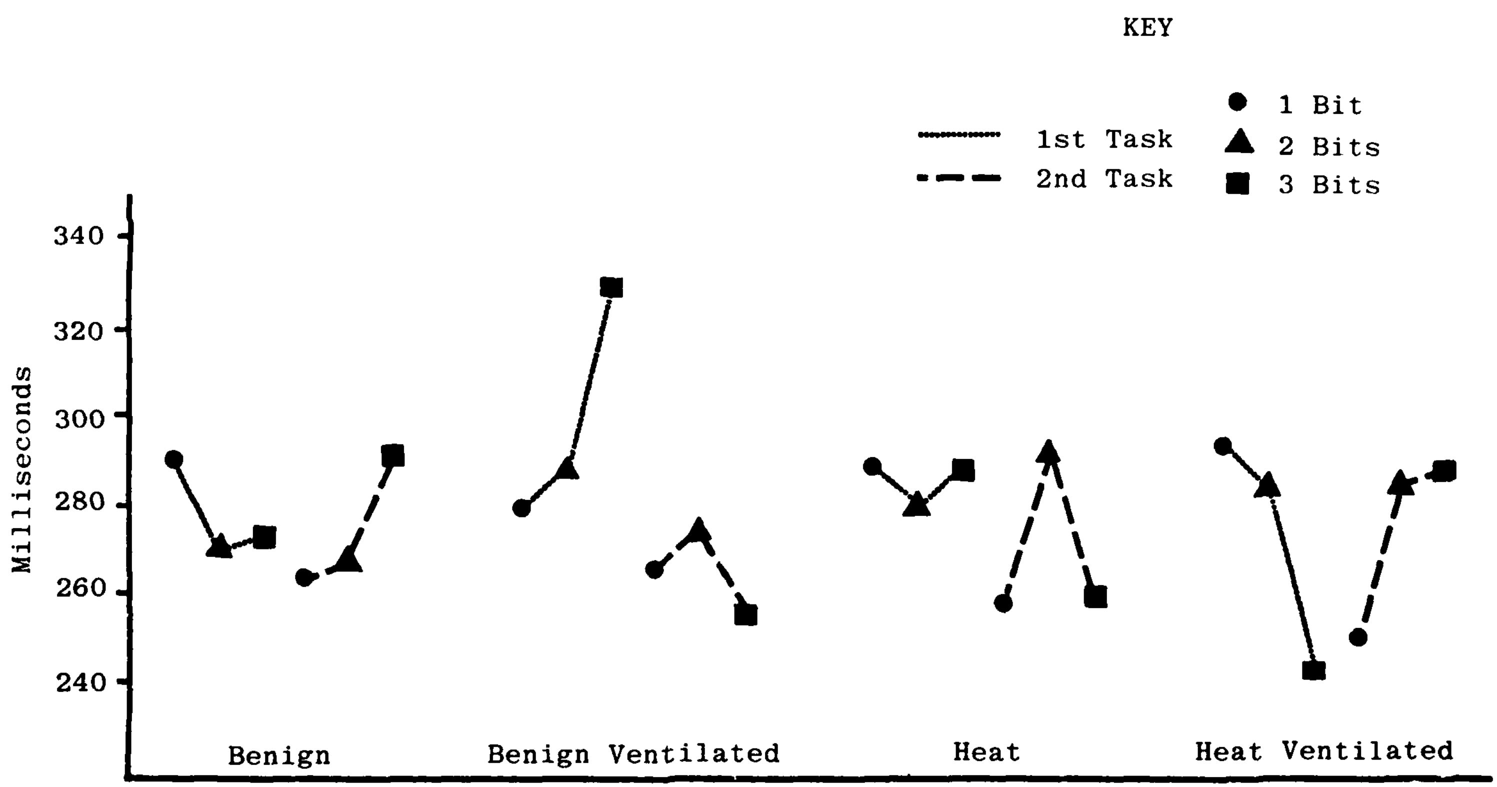

Figure 14. Mean Preexposure Movement Times

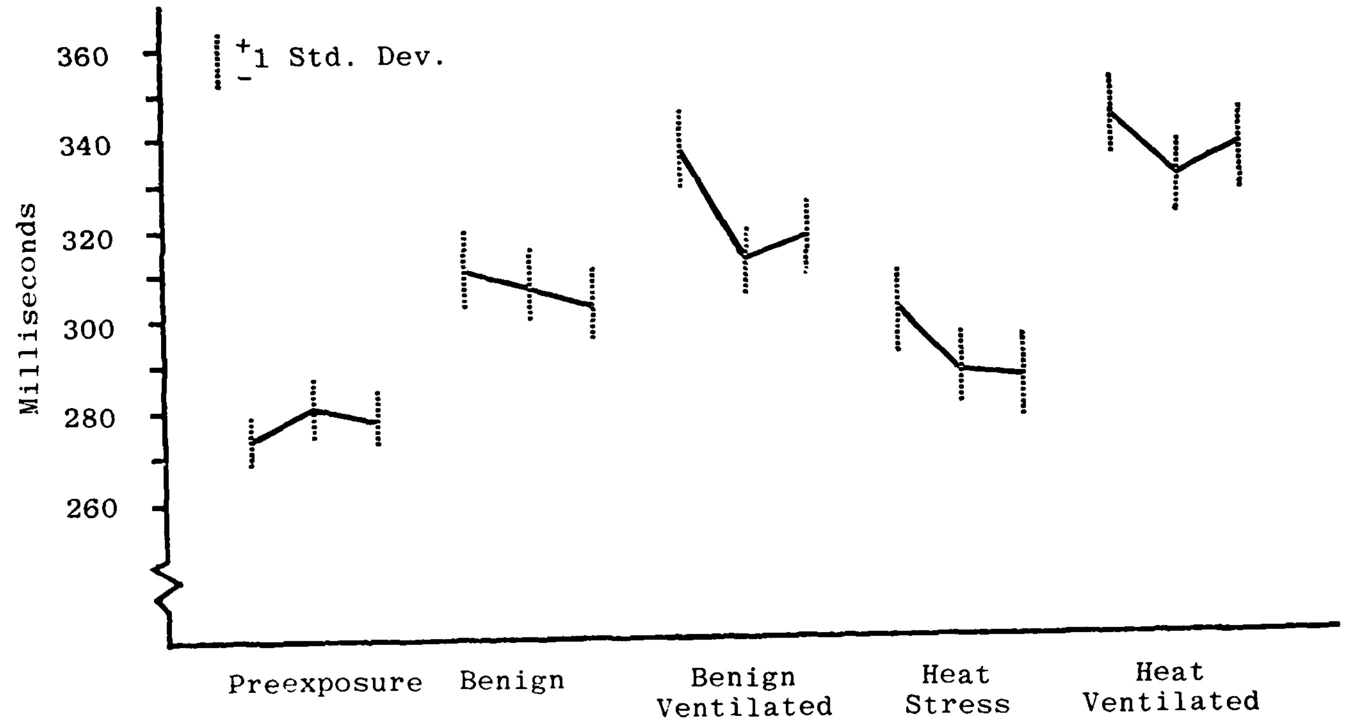

Figure 15. Mean Movement Times

TABLE 13
TESTS ON BITS MEANS USING NEWMAN-KEULS PROCEDURE MOVEMENT TIME DURING EXPOSURE

Bits		Two	Three	One
Ordered Means		.310126	.311075	.324001
		Two	Three	One
Differences between pairs	Two		.000948	.013874
	Three			.012926

	r =	2	3
$S_{\bar{B}} = .003624$			
$q_{.95}(r,10)$		3.151	3.877
$S_{\bar{B}}q_{.95}(r,10)$		.011269	.014050
$q_{.90}(r,10)$		2.563	3.270
$S_{\bar{B}}q_{.90}(r,10)$		.009288	.011850

	Two	Three	One
Two			*
Three			*

* $p < .10$

Figure 15 shows the means and standard deviations of movement responses to each stimulus level in each environmental condition. Also shown is the same information for all preexposure movement responses combined. The values reflected in Figure 15 represent mean responses across morning and afternoon performance and across the different time periods when performance was measured.

Two within subjects main and two interaction effects were significant at the 5% level or less. The interaction terms were further examined through determination of respective simple effects. An extract of the ANOVA summary reflecting these significant findings and incorporating the simple effects appears as Table 12. The extract includes only those factors having F ratios significant at the 5% level or less. The complete summary appears in Courtright (1976).

A significant main effect was found for bits; i.e., response differences related to the information content of the input stimuli. The mean movement time for each bit level appears on Table 13. This main effect was significant at the 5% level. Newman-Keuls tests of the differences between the mean bits responses failed to verify significant differences at the same level of significance. They did, however, indicate that the mean movement response for one bit stimuli differed from the mean responses for both the two and three bits stimuli at the 10% level. No difference was found between the responses for the two and three bits stimuli. This finding was inconsistent with preexposure behavior where movements in response to one bit stimuli were somewhat faster than to two or three bits stimuli. Welford (1968) observed that there is commonly little or no correlation between reaction time and movement time. This research suggested negative relationship.

Examination of the task apparatus suggested a possible explanation for the differences found. The apparatus was laid out in a semicircle with all switches and stimulus lamps equidistant from the null switch and all equidistant apart. Size and shape of switches and lamps was the same for all eight stimulus and response positions on the apparatus. The stimulus displays (i.e., extinguished lamps) for one bit stimuli appeared in one of four positions to the right or left of center on the same plane with and directly opposite the remaining illuminated stimulus lamp. The stimulus displays for two bits stimuli were presented in one of three positions. The displays for three bits stimuli could appear in any one of the eight positions, but its switch was adjacent to the only extinguished lamp in the array. Visually guided movements, such as to the response switches of the task apparatus, involved visual feedback and correction (Pew, 1974; Welford, 1968). Although all target switches were identical in size, shape, and distance from the null switch, movement towards the three bits stimuli response switches provided the smallest visual "window" containing the target switch. Since only one lamp was extinguished the visual feedback information was most precise. The amount of corrective action required within the window while the hand was in motion should therefore have been the least of the stimulus states. On the other hand, the one bit response should have required the greatest correction since, in general, they had the largest visual window containing a target switch. Therefore, responses to one bit stimuli should have been longest, to three bits stimuli least, and to two bits stimuli somewhere in between. This was not the case, however. Movement responses to one bit stimuli were the longest, but there was no essential difference in movement times in response to the two and three bits stimuli. This suggested that the additional breadth of the visual window remaining displayed on the apparatus during movement responses to two bits stimuli was not significantly different from that available for three bits stimuli. This contention about the visual window has been offered only as a possible explanation. There was no way to verify it from the research data analyzed.

The findings of the simple effects tests for the Heat x Ventilation interaction revealed that ventilation had a significant impact on movement responses in the high temperature conditions but none in the benign. This was indicated by the simple main effect of V at H_2, which was significant at the 0.5% level and the simple main effect for V at H_1, which was not significant. Mean values for this interaction appear in Table 14. These findings clarified the significant Ventilation main effect. Wearing of the ventilating helmet increased the movement times of the subjects under both heat conditions. However, this time lengthening was significant only when the body was subjected to the high temperature stressor while the head was simultaneously being cooled.

TABLE 14
MEAN VALUES FOR MOVEMENT TIME HEAT x VENTILATION INTERACTION

Environment	Unventilated	Ventilated
Benign	308	323
Heat	293	337

There were two possible explanations for the time lengthening. One was an artifact of the experiment itself. The other was related to the physiological arousal level of the subjects.

The ventilating helmet was counterbalanced so that its weight was not borne by the subjects. It did, however, limit their freedom of movement somewhat. In addition, the hoses supplying cool air entered the helmet on each side above and slightly behind the subjects' shoulders. While moving to respond to the stimulus, the hoses would frequently touch the shoulders. This jarred the helmet causing it to be moved slightly. This happened to each of the subjects and each commented on it. It is possible that this bumping, by providing distracting kinesthetic information, interfered with the feedback correction, thus lengthening the movement times.

The greatest physiological arousal level in this experiment occurred in the heat stress tests; the lowest was in the benign ventilated tests. This conclusion was based on the physiological indicators of core and skin temperature and reports by the subjects that they found the latter condition to be the most difficult in which to maintain attention to the demands of the tasks. Therefore, since heat exposure initially causes faster movement time, which later is slowed as the subject becomes over-aroused, and since under-arousal also tends to slow movement, this could be checked in the analysis. If arousal had been responsible it should have appeared as a change over time in both condtions with the fastest movement in the early part of the heat stress tests. In the benign ventilated tests the movement time would also have been slowed over time because of the increasing under-arousal. This was not supported by these data. Instead, the ventilation effect was significant only for heat stress as revealed by simple effects analyses of the Heat x Ventilation interaction. In the heat ventilated tests subjects' arousal levels for kinesthetic stimuli were high. Therefore, the most plausible explanation for ventilation effects found is that they were an artifact of the experimental apparatus.

Simple effects were also determined for the Diurnal x Heat interaction, signifcant at the 5% level. None of the interaction differences were found to be significant in the simple effects analyses.

Little could be generalized about environmental influences on reaction time task movement from this research. The preexposure data showed considerable variation and were probably confounded by being initial responses after varying periods of time without practice on the task. The data collected during the exposure tests seemed to be contaminated by artifacts arising from apparatus design.

THE TRACKING TASKS

Prior to the subjects' preparation for entry into the environmental chamber they completed two sets of five trials on each of the tracking tasks. During the tests within the chamber, five sets of four measurements of each tracking task were completed.

PRETEST FAMILIARIZATION

The effective time constants determined for these performances were subjected to an ANOVA with repeated measurements on each factor and subject. The within subjects were: (1) the difficulty of the tasks, an order effect; (2) a diurnal effect; (3) knowledge of the environmental condition in the test to follow; and (4) a time effect, whether the tasks were in the first or second set of measures.

Significant differences were found in the Task Difficulty main effect, and in the Order x Diurnal interaction term. Table 15 contains the mean effective time constant values for the Order x Diurnal interaction. An extract of the ANOVA summary for these factors, together with the simple main effects of the interaction, appears as Table 16. The complete summary appeared in Courtright (1976).

TABLE 15
MEAN EFFECTIVE TIME CONSTANT VALUES FOR PREEXPOSURE TRACKING TASKS ORDER x DIURNAL INTERACTION

Task Order	Mean AM Performance	Mean PM Performance	Mean Order
Position Tracking	134	134	134
Rate Tracking	183	173	178
Mean Diurnal	158	153	

NOTE: Values reported to the nearest millisecond.

TABLE 16
EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR PREEXPOSURE TRACKING TASK PERFORMANCE

Source of Variance	df	MS	F	p
Between Subjects	5	.18478	616.000	< .001
Error	768	.00030		
Within Subjects	186			
O (Task Difficulty)	1	.47055	9.101	< .05
Error	5	.05170		
O at D_1	1	.28778	11.080	< .01
O at D_2	1	.18805	7.241	< .05
Error	10	.02597		
D (Diurnal)	1	.00585	1.700	ns
Error	5	.00344		
D at O_1	1	.00001	< 1	ns
D at O_2	1	.011113	6.115	< .05
Error	10	.00184		
O x D	1	.00528	21.913	< .01
Error	5	.00024		

The expected greater difficulty of the rate control task was confirmed by the analysis. It also revealed that competence in performing the tasks did not change significantly over the duration of the data collection period resulting from the added practice in task performance. In addition, performance was not significantly influenced by knowledge of the stressor to be used in the tests.

The simple main effects for the diurnal effect (i.e., morning versus afternoon performance) indicated an impact only for the more difficult task. Although afternoon performance was slightly better for both tracking tasks, the difference in mean effective time constants was markedly different. The mean difference for the simpler tracking task was .246 milliseconds, a difference that was not statistically significant. The mean difference for the more difficult task was 9.629 milliseconds; this difference was significant at the 5% level.

Performance on the more difficult rate compensation tracking task was the only performance measure that revealed a systematic diurnal variation during these pretests. This was a difficult task. It required the subjects to perform at the very edge of their ability, leaving little reserve capacity. This finding revealed that the subjects were consistently better able to track the more difficult task in the afternoon, even though this was, on the average, but 3 hours later in the day. Afternoon measures were typically recorded at approximately 1:15 PM and 1:25 PM, respectively.

No physiological state data were collected during the preexposure testing. Values recorded approximately 30 minutes later revealed the mean rectal temperatures were 36.88°C in the morning and 37.22°C in the afternoon. Thus, in terms of the "normal" core temperature of 37°C, the arousal level of the subjects should have seen somewhat greater in the afternoon than in the morning. With the less demanding task this was enough to cause significant performance differences; however, for the more difficult rate compensation tracking task it may have been.

TRACKING DURING EXPOSURE

The overall mean performance for position and rate tracking measured over the various times the data were collected during the tests is depicted in Figure 16. Further depictions of performance and tables of mean performance related to specific factors analyzed appear later adjacent to the narrative description of the significant findings under discussion. The effective time constants for the five sets of measures within the chamber were examined by ANOVA with repeated measures on each factor and subject. The within subjects factors were (1) the difficulty of the tasks, on order effect; (2) a diurnal effect; (3) the environmental heat level (4) whether or not the subject's head was ventilated; and (5) the time which had elapsed since entering the chamber.

Three main effects, one 2-factor interaction, and one 4-factor interaction found to be significant at the 5% level or less. The 2-factor interaction, Order x Diurnal, was further tested for simple main effects. The ANOVA and simple effects summary are extracted in Table 17.

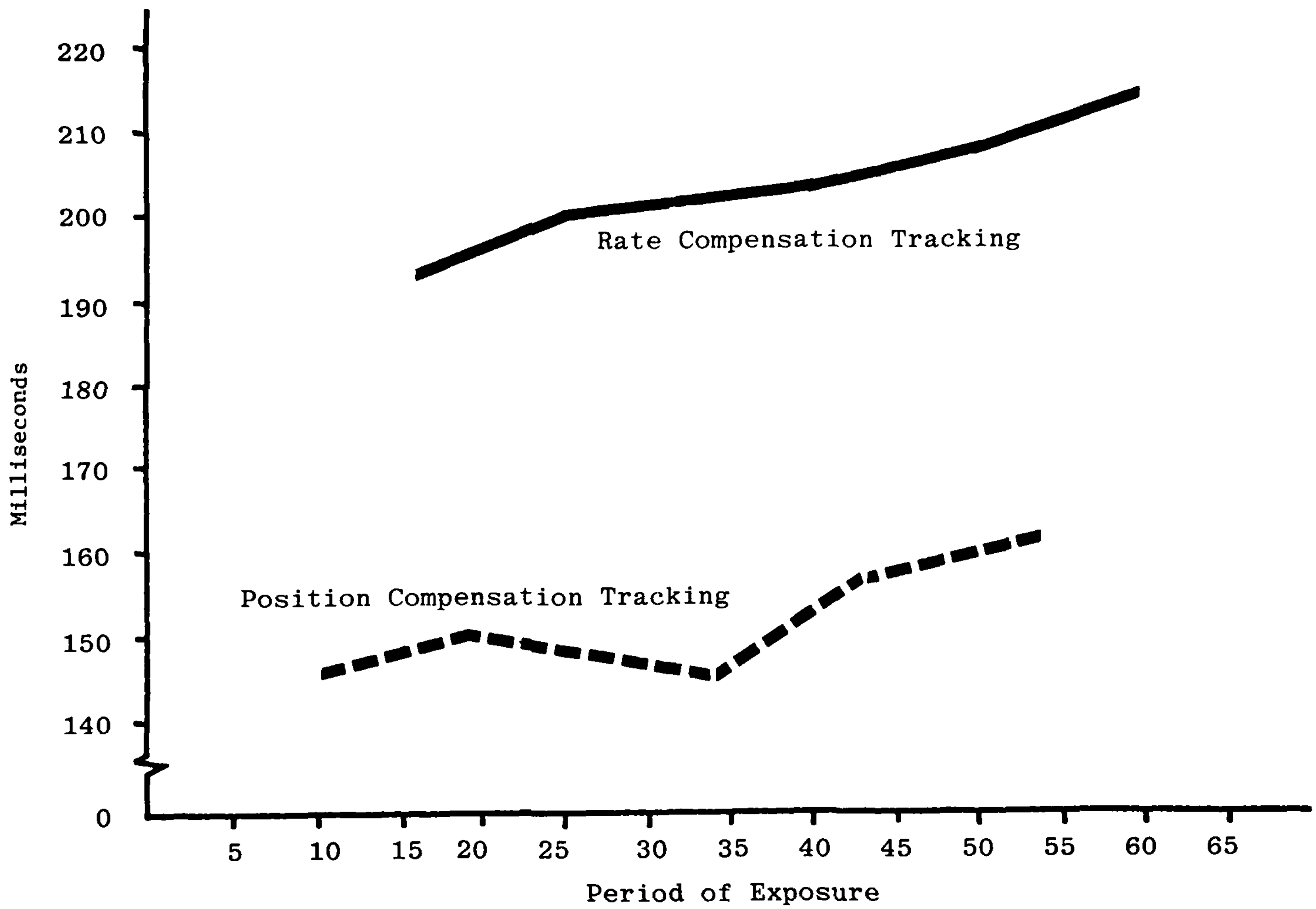

Figure 16. Mean Effective Time Constant Values

TABLE 17
EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR TRACKING TASKS DURING EXPOSURE

Source of Variance	df	MS	F	p
Between Subjects	5	.40569	863.170	< .001
Error	1440	.00047		
Within Subjects	474			
O (Task Difficulty)	1	1.30505	22.862	< .005
Error	5	.05708		
O at D_1	1	.76076	26.110	< .001
O at D_2	1	.55240	18.959	< .005
Error	10	.02914		
D (Diurnal)	1	.06065	6.083	< .10
Error	5	.00997		
D at O_1	1	.01201	2.152	ns
D at O_2	1	.05699	10.215	< .01
Error	10	.00558		
O x D	1	.00834	7.016	< .05
Error	5	.00119		
T (Time)	4	.02056	7.968	< .01
Error	20	.00258		
. . . . .				
O x H x V x T	4	.00129	3.022	< .05
Error	20	.0043		

The Task Difficulty main effect was significant at the 0.5% level, which confirmed the preexposure observation that the two tasks involved differed in their performance difficulty. The simple main effects for task difficulty at the two times of day during which the tests were conducted further confirmed this observation.

The simple main effects for diurnal variation repeated the findings noted for preexposure performance. The simple main effect for diurnal variation was significant only for the rate compensation tracking task. The mean effective time constants for both tracking tasks were faster in the afternoon. For the simpler task the difference was approximately 7 milliseconds. For the rate tracking task it exceeded 15 milliseconds.

No post hoc analysis of the significant 4-way Order x Diurnal x Ventilation x Time interaction was accomplished. Considering the number of subjects involved in the study, further statistical analyses were not expected to yield meaningful information. A graphic presentation of the mean values in that interaction appears as Figure 17, which suggests that the principal operating factors were order of difficulty of the task and diurnal variation in the rate compensation tracking task. Further interactions do appear for both orders of task difficulty; however, the impact appears to have little practical significance. The figure suggests the significant main effect finding that elapsed time from the beginning of exposure was probably a more significant variable for both tasks. This is discussed in more detail in the following description of further analyses that were accomplished.

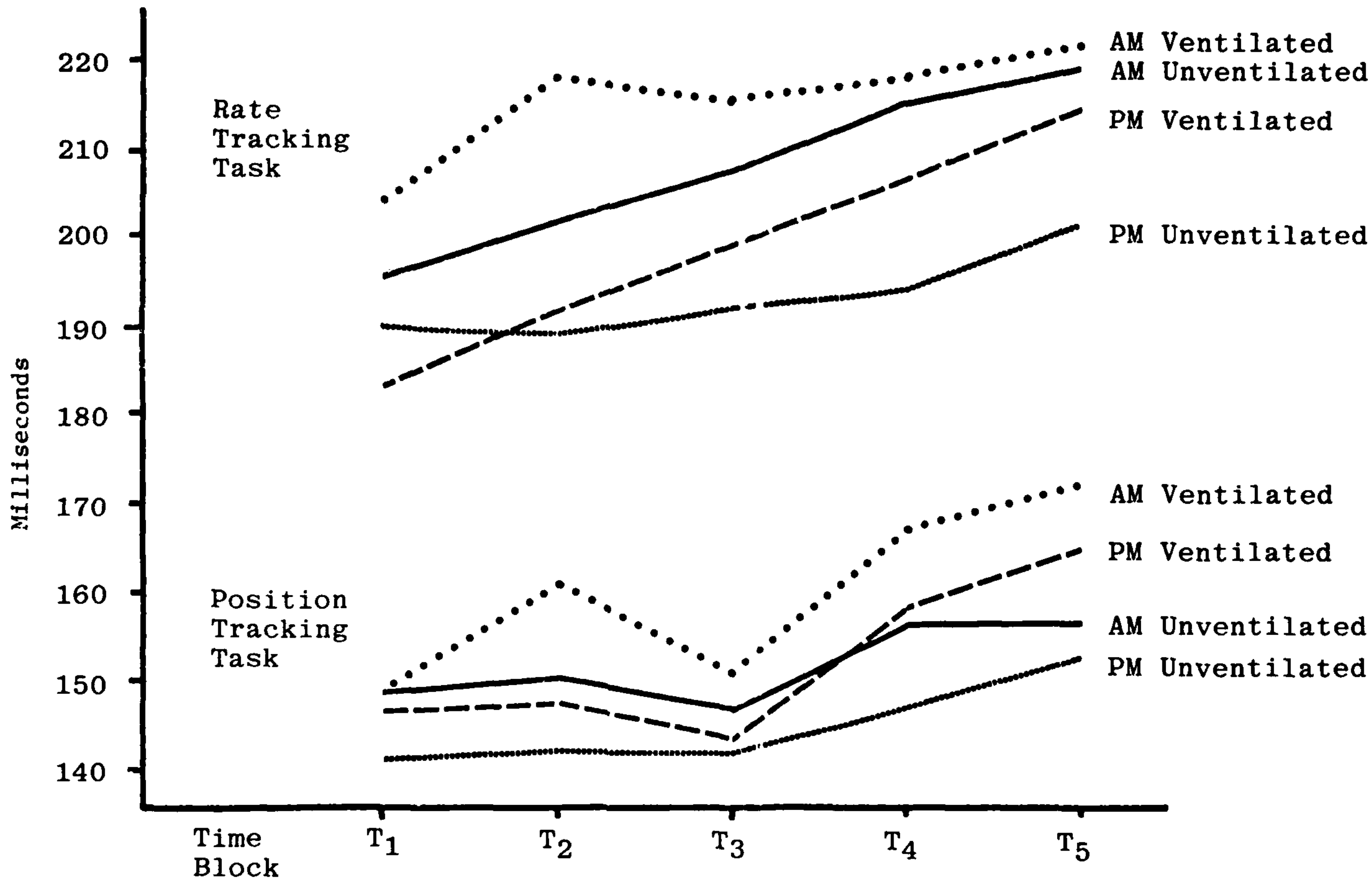

Figure 17. Mean Effective Time Constants for Order x Diurnal x Ventilation x Time Interaction

Because of the significant impact of the order of task difficulty upon the subjects' performance, separate analyses of variance were prepared for position compensation tracking performance and for rate compensation tracking performance. The within subjects factors considered in both analyses were the same. These were (1) a diurnal factor, (2) the level of the environmental heat stressor, (3) whether the heads of the subjects were ventilated, and (4) the passage of time after the tests began.

POSITION COMPENSATION TRACKING TASK PERFORMANCE

Figure 16 contained a depiction of overall position tracking performance. The ANOVA completed for the position compensation tracking task revealed a main effect for time passage which was significant at the 1% level. A further test of the Time effect was made using the Newman-Keuls procedure. Mean values at each time block together with a report of these tests appear in Table 18. The Newman-Keuls procedure revealed that performance on the task during the last data collection period, approximately 58 minutes after the periods began, differed from performance on the three trial periods during the first 33 minutes after entering the chamber. This difference was significant at the 5% level. No other significant differences were found for the position compensation tracking task performance. There was no indication that tracking behavior changed consistently because of the thermal stressor, ventilation of the head, or the diurnal variation. The significance of the 4-way interaction for the position compensation tracking task depicted in Figure 17 was not confirmed in this analysis.

TABLE 18
TESTS ON TIME BLOCKS MEANS USING NEWMAN-KEULS PROCEDURE POSITION COMPENSATION TRACKING TASK DURING EXPSOURE

Time Blocks		T_3	T_1	T_2	T_4	T_5
Ordered means		.145104	.146214	.150281	.157573	.162000
		T_3	T_1	T_2	T_4	T_5
	T_3		.001109	.005177	.012469	.016896
Differences	T_1			.004068	.011359	.015786
between pairs	T_2				.007292	.011719
	T_4					.004427

	r	2	3	4	5
$S_{\bar{T}} = .003257$					
$q_{.95}\,(r,20)$		2.95	3.58	3.96	4.23
$S_{\bar{T}}\,q_{.95}\,(r,20)$		.009609	.011661	.012899	.013778

	T_3	T_1	T_2	T_4	T_5
T_3		.	.	.	*
T_1			.	.	*
T_2				.	*
T_4					.

* $p < .05$

Further analysis of the effects over time on the tracking performance scores was accomplished through determination of the goodness of fit of linear and quadratic polynomial regressions for each of the thermal exposure conditions. No significant contribution to describing changes as a result of improvement in sums of squares was provided through these regressions for any of the conditions.

Position tracking performance deteriorated over the test duration. This finding ruled out performance differences due to arousal level, if arousal is a function of physiological state variation of either core temperature change or of some combination of core and skin temperature change. These differed markedly under the various test conditions. A more plausible hypothesis to account for the observed difference over time would seem to be fatigue. The somewhat better performance at T_3 (33.5 minutes - 36 minutes) may well have been the first sign of oncoming fatigue. Such a phenomenon was reported previously (Welford, 1968).

The nature of the task was such as to compel the subject to generate neuromuscular gain dynamics to perform successfully. Subjects did this better during the initial 36 minutes of the tests than during the subsequent 20 minutes. Deterioration in performance during the tests was analogous to an increase in the transmission lag in a servomechanism (Poulton, 1974). The mean change in that transmission lag between task performance at approximately 36 minutes from that at approximately 56 minutes was + 16.9 milliseconds.

There is no way to be certain why change associated with the thermal stressor was not observed in this research when previous studies of compensatory tracking had found such effects (Smiles et al., 1975; Iampietro et al., 1969; Grether et al., 1971; Azer et al., 1972). Except for the Smiles et al. (1975) study, each employed simultaneous visual monitoring of reaction time tasks requiring manual responses in addition to tracking. The requirement to respond to these additional task loads diminished the subjects' capacity to maintain tracking proficiency (Poulton, 1970). This showed up in diminished tracking performance.

Smiles et al. (1975) exposed subjects to 65 minutes exposure of heat stress at 50°C, 34°C Effective Temperature. They used a variation of time-on-target scoring involving hits-on-target. To score a "hit" required a dwell time of 330 milliseconds in various window dimensions. The hit scores were slightly better (significant at the 5% level) during heat exposure when the task dynamics simulated "stable" aircraft plant dynamics. However, when the subjects' tracking performance was used to determine subject transfer functions, no effects of heat per se were observed. When the task dynamics simulated "unstable" aircraft plant dynamics, direct effects of heat were noted in the changes in gain, phase angle curves, and worsening bandwidths indicating higher frequency overcontrol characteristics. With both task dynamics, performance decreased whether the subjects were in heat or not. No significance level was reported for this, and no further discussion was included in their report. It was difficult to make direct comparisions with this work because of the limited information presented about the task. However, changes in human operator dynamics of the type cited for the unstable aircraft would appear as increases in the subjects' effective time constants had that been the metric employed.

In summary, there are several conclusions that can be made about position compensation tracking in heat. First, when such tracking is the sole task, performance tends to be little affected by heat stress per se of the magnitude employed in this study through 56 minutes of exposure, unless the task plant dynamics are also made difficult. Second, fatigue due to time passage is a more imposing stressor than heat of the level used in this study.

TABLE 19
SELECTED MEAN VALUES FOR RATE TRACKING TASK PERFORMANCE DURING EXPOSURE

Test Measurement Period	AM Performance			PM Performance		
	Benign	Heat	Mean	Benign	Heat	Mean
1 (15'30" - 18')	190	211	201	188	186	187
2 (25'30" - 28')	200	221	210	185	197	191
3 (40' - 41'30")	209	215	212	190	202	196
4 (50' - 52'30")	212	222	217	195	207	201
5 (60' - 62'30")	217	224	220	205	212	209
Mean Values	206	219	212	193	201	197

Note: Values reported to the nearest millisecond.

TABLE 20
EXTRACT FROM SUMMARY OF ANALYSIS OF VARIANCE FOR RATE COMPENSATION TRACKING TASK DURING EXPOSURE

Sources of Variance	df	MS	F	p
Between Subjects	5	.36334	564.28	< .001
Replications within Cells	720			
Within Subjects	234			
D (Diurnal)	1	.05698	7.409	< .05
Error	5	.00769		
H (Heat)	1	.02821	4.228	< .10
Error	5	.00667		
T (Time)	4	.01189	9.998	< .001
Error	20	.0019		

RATE COMPENSATION TRACKING TASK PERFORMANCE

The ANOVA prepared using the rate tracking data showed performance to be more sensitive to the variables under investigation than was seen with position compensation tracking. Selected mean effective time constant values related to the significant effects appear in Table 19. An extract of the ANOVA summary table for rate compensation tracking appears in Table 20.

Performance differences were found to be attributable to diurnal influences, significant at the 5% level. The diurnal variations were also noted above in discussion of the ANOVA performed which included data from both tracking tasks. Rate compensation tracking performance during the afternoon periods was significantly better than morning performance. The magnitude of that difference can be observed in Table 19.

The effect of the passage of time during the conduct of the several measurement periods was found to be significant at the 0.1% level. This was further analyzed using the Newman-Keuls procedure. The mean values for the five time periods appear in Table 21 with the report of the Newman-Keuls tests. With one exception, Newman-Keuls tests revealed that passage of 20-25 minutes time caused a significant performance decrement. The exception was the 25 minutes of elapsed time between the second and fourth measurement periods. No other differences were found to be significant. Thus, there was no indication that behavior was significantly influenced by the ventilating of the head or by the magnitude of the thermal stressor.

Further analyses of the effects over time on the rate compensation tracking performance scores were accomplished by determining the goodness of fit of linear and quadratic polynomial regressions for each of the thermal exposure conditions. Separate regressions were prepared for the morning and the afternoon exposures. No significant contribution was provided to describing changes as a result of improvement in sums of squares through these regressions for any of the conditions.

Finding a significant diurnal effect during both the preexposure and exposure tests suggested this exerted a persistent influence on performance effectiveness. This supports the recommendation of Poulton and Edwards (1974) that psychomotor performance measurement should be made at the same time of day. For both preexposure and exposure performance measurement on this task, afternoon performance was superior. Mean improvement in the preexposure and exposure tests effective time constants was approximately 10 and 15 milliseconds, respectively.

Mean rectal temperatures were 0.34°C higher in the afternoon than in the morning. In each test condition, the afternoon temperatures were higher than the corresponding morning temperatures. This diurnal difference, when considered with the somewhat poorer performance under the heat stress condition, tended to support Provins (1966) contention that the subjects were more highly aroused during the afternoon test than during the morning tests and that the further increase in arousal led to poorer performance. Performance under heat stress showed some deterioration, though the significance of that change ($p < .10$) was not sufficient to confirm that the heat exerted a strong influence.

Mean rectal temperatures in the morning and afternoon heat stress conditions were initially less than the preexposure values. They reached the preexposure level after approximately 30 minutes of exposure. By the end of the final task set they had been raised approximately 0.5°C above the preexposure level. In the benign conditions, mean rectal temperatures were approximately 0.3°C less than the preexposure level and remained less than the preexposure levels throughout.

dropping a further 0.1°C during the final 30 minutes. Thus, in comparing the two basic thermal influences, a divergence in core temperatures was found, which was initially about 0.2°C. After 30 minutes it had widened to approximately 0.3°C. It was approximately 0.9°C during final task performance. This suggested that Provins' (1966) hypothesis relating performance and arousal level may have been supported by this research. Performance deteriorated over time in both thermal environments, although it was somewhat better in the benign conditions. If body temperature is related to arousal level in the way Provins has suggested, the subjects were progressively more aroused in the heat conditions and were less aroused at the conclusion of the benign tests than in the beginning. Therefore, changes in performance on the rate compensation task over time may have followed the Yerkes-Dodson inverted-U curve, with benign performance declining because of under-arousal while performance in heat worsened from over-arousal. Unfortunately, these data do not confirm or deny this possibility. One way to have done this would have been to examine changes in the nature of the describing functions themselves. That would require an additional study and the recording of appropriate metrics to enable such analyses to be accomplished.

Changes in performance over time were very regular for rate compensation tracking. Unlike performance on the position compensation tracking task, there was no "breakpont" such as had been observed in that simpler task. The mean change in effective time constants from the first block to the fifth time block was approximately 7, 9, 10, and 21 milliseconds, respectively. Moreover, the general characteristic of change occurred progressively in both morning and afternoon tests and in both benign and heat stress environments. The change was reasonably regular, implying a relatively stable impact on performance of a progressive influence which was most likely due principally to fatigue. The task itself was demanding, requiring the subjects to generate lead as well as gain dynamics. During the intratask intervals, the subjects performed

TABLE 21
TESTS ON TIME BLOCKS MEANS USING NEWMAN-KEULS PROCEDURE RATE COMPENSATION TRACKING TASK DURING EXPSOURE

Time Blocks		T_1	T_2	T_3	T_4	T_5
Ordered means		.193849	.200615	.203911	.209141	.214370

		T_1	T_2	T_3	T_4	T_5
Differences between pairs	T_1		.006766	.010063	.015292	.020521
	T_2			.003297	.008526	.013755
	T_3				.005229	.010458
	T_4					.005229

		$r =$ 2	3	4	5
$S_{\overline{T}} = .002488$					
$q_{.95}\,(r,20)$		2.95	3.58	3.95	4.23
$S_{\overline{T}}\,q_{.95}\,(r,20)$		.007340	.008907	.009852	.020524
$q_{.99}\,(r,20)$		4.02	4.64	5.02	5.29
$S_{\overline{T}}\,q_{.99}$		.010002	.011544	.012490	.013161

	T_1	T_2	T_3	T_4	T_5
T_1		.	*	**	**
T_2			.	.	**
T_3				.	*
T_4					.

** $p < .01$
* $p < .05$

other tasks that also demanded careful and continued attention. This may have reduced the subject's ability to recover between tasks. In short, the data suggested that rate compensation tracking performance can be expected to deteriorate steadily where such tracking is performed periodically over an hour's time, and where intratask intervals are occupied with performance of other tasks such as those employed in this research.

In both position and rate compensation tracking, the principal influence on performance effectiveness noted in this research can probably be attributed to subject fatigue. In addition, the demands of the rate compensation tracking tasks were such that performance competence was influenced by the time of day during which the task was performed. Moreover, performance of this task may be sensitive to heat stress influences, although that was not firmly established by this research. However, when the diurnal differences and the possible heat effects were considered together in light of differences in arousal as indicated by body temperature, it appeared that optimal performance of this task may have been achieveable only over a narrow range of arousal levels.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF RESEARCH OBJECTIVES

The objective of this research was to determine the time course of effects of two environmental heat stressors on four human performance measures. The environmental stress conditions were unprotected exposure to heat of 65.6°C; and exposure to the same heat environment where the subjects' heads and necks were cooled by circulating air at the temperature of 15.6°C. Environmental humidity was maintained at 10 mm Hg partial water vapor pressure. The four performance meaures were (1) mental arithmetic accuracy; (2) position compensation tracking; (3) choice reaction time; and (4) rate compensation tracking. In addition, an objective of this study was to determine whether performance differences resulted from the tasks being performed at two different times of day. This section has been organized into (1) Review of the Literature; (2) Research Method Employed; and (3) Results.

SUMMARY OF THE LITERATURE REVIEW

Changes in performance under high temperature stress have been inconsistent, because of differences in thermal stressor level, complexity of the performance tasks employed, and duration of observation. In gerneral, where the time and temperature levels of exposure approach the level of physiological tolerance, consistent decrements have appeared (Wing, 1965).

Heat exposure causes greater movement activities, such movements being initially slightly quicker, and later in the exposure being slower than in preexposure benign environments. This is found in reports of reaction time (Kleitman et al., 1938; Fraser and Jackson, 1955) and tracking performance (Pepler, 1960).

Heat causes, at least initially, a tendency to respond more quickly, though generally with less accuracy. This has been observed in subject paced position prediciton (Bartlett and Gronow, 1953), signal detection (Wilkinson et al., 1964; Poulton and Kerslake, 1965), self-paced complex tests (Allnutt, 1969), reaction time (Kleitman et al., 1938; Broadbent, 1963; Pepler, 1959), and tracking (Pepler, 1959, 1960). However, where the nature of the task requires coordinated eye-hand manipulation, the tendency to respond more quickly diminishes with the passage of time. As the length of exposure to a heat stressor causes the subjects to approach their physiological tolerance, time to respond in heat becomes longer than it was in the preexposure environment and the number of errors becomes progressively greater. This effect appears both with reaction time task performance (Pepler, 1953; Fraser and Jackson, 1955; Azer et al., 1972) and with tracking (Blockley and Lyman, 1951; Pepler, 1959).

Heat may sharpen attention to essentially mental tasks while simultaneously reducing capacity to handle multiple or complex stimuli, perhaps through limitation on short term recall. This effect appears on tasks of auditory and visual vigilance (Pepler, 1958; Wilkinson et al., 1964; Colquhoun and Goldman, 1972), auditory recall (Wing and Touchstone, 1965), speeded symbol discrimination (Pepler, 1958), telegraphy signal interpretation (Pepler, 1953, Mackworth, 1950, 1961), mental addition (Wing, 1965), and mental addition to a referenced total (Blockley and Lyman, 1950).

Those subjects possesing great skill or inherent ability show less decrement under heat stress than do their less qualified colleagues. This effect has been noted in speeded symbol discrimination (Chiles, 1958a, 1958b; Pepler, 1958), telegraphy signal interpretation (Pepler, 1953; Mackworth, 1961, and tracking (Blockley and Lyman, 1951).

Where mental arithmetic task metrics were sensitive to accuracy of performance and the exposure time was fairly lengthy, decrements in performance typically have been found in heat stress environments. Blockley and Lyman (1950) found clear indication of performance decrement under heat and time conditions similar to those in this research. Givoni and Rim (1962) found performance decrements towards the end of their tests. Fox et al. (1963) found mental arithmetic performance to be affected by variations in body temperature. The implications from the literature with respect to the influence of head cooling on mental arithmetic performance have not been clear. Studies reported by Konz and Kentwich (1969) and by Kissen et al. (1974) did not indicate performance change. However, both used lower heat levels and Konz and Kentwich used mental arithmetic productivity as their dependent variable. The literature implied that differences in mental arithmetic accuracy performance may have been related to subject arousal level. This was supported by the Provins (1966) and Provins et al. (1974) suggestions relating arousal level to body temperature and by the work of Givoni and Rim (1962), Fox et al. (1963), and by the conclusions of Wulfeck and Zeitlin (1962).

Reaction time task performance has been affected by heat stressors of the level used in this research. In 1983, Kleitman et al. found both simple and choice reaction time to be affected by body temperature changes induced through diurnal influence. Fraser and Jackson (1955) found differences in serial reaction time performance in moderate heat stress where the humidity was high. Bursill (1958) studies responses to a simple reaction time task performed simultaneously with tracking under temperature conditions of 35°C. Azer et al. replicated the Bursill study in 1972. In these studies reaction time was lengthened and errors increased in heat stress when the tracking task was a fairly demanding one. Lengthened response results were also obtained by Grether et al. (1971) who looked at choice reaction time performed simultaneously with tracking in 48.9°C heat. There were no reports of studies of the effects of head cooling on choice reaction time performance. However, in 1971, Benor and Shvartz used a forewarned simple reaction time task while cooling the whole body in heat as great as 50°C. No effects were found for either the heat stressor alone or for cooling when compared to heat performance. Reaction time task performance may be influenced by arousal level changes brought on by variations in internal body temperature. Body temperature changes resulting from diurnal variation were suggested by Kleitman et al. (1938) to influence performance adversely.

The effects of heat on the movement time component of choice reacton time must be surmised. The studies reviewed do not address movement time apart from reaction time. The studies of Kleitman et al. (1938), Fraser and Jackson (1955), and Azer et al. (1972), suggested that movement time may be initially faster under a heat stressor but that later in the exposure it is likely to slow.

Iampietro et al. (1969) found no differences due to heat on the vertical dimension of a two-dimensional compensatory position tracking task with simultaneous additional monitoring and arithmetic tasks. Differences in horizontal tracking were found but they were due to the cross-coupling of the tracking hand with responses required to the other tasks. In this study, the exposure was for approximately 30 minutes in temperatures ranging to 71.1°C. In 1971, Grether et al. employed a two-dimensional position tracking task in 48.9°C. The task was performed simultaneously with choice reaction time and voice communication tasks. Vertical tracking performance was affected by Heat. Horizontal tracking may also have been affected; the significance level observed for horizontal tracking was at the 10% level. Azer et al. (1972) reported position compensation tracking performance deterioration at the end of a 1-hour exposure to 37.8°C heat. Smiles et al. (1975) exposed subjects to heat of 50°C. Hits-on-target for tracking tasks with relatively stable forcing function dynamics were slightly better under heat, but there was no change in derived subject describing functions. Performance worsened when tracking with an unstable plant dynamic forcing function. Derived describing functions showed changes under heat in gain, phase angle, and bandwidth. Changes in arousal level would be more likely to impact rate compensation tracking performance than position compensation tracking. When task dynamics were difficult or several tasks were performed simultaneously, performance has tended to be affected adversely (Smiles et al., 1975; Grether et al., 1971; Azer et al., 1972).

SUMMARY OF THE RESEARCH METHOD

Six right-handed male Air Force personnel served as subjects. They repeatedly performed four tasks during 66 minutes testing periods under four thermal conditions. They were tested twice under each thermal condition, once in the morning and once in the afternoon. The thermal conditions were (1) a benign control (26.6°C); (2) a benign condition where the head and neck were ventilated with air of the same temperature (26.6°C); (3) a heat stress condition (65.6°C); and (4) a heat stress condition (65.6°C) where the head and neck were ventilated with cool air (15.6°C). Humidity was maintained for all conditions at 10 mm Hg partial water vapor pressure.

Before each test the subjects performed a prescribed practice on the task outside the chamber to stabilize their performance before the exposure tests. During each test they wore physiological monitoring sensor devices, clothing of approximately 1 clo insulation, and a cotton glove on the right hand. During the conditions involving head ventilation, the subjects wore earplugs to attenuate increased noise.

All tests were conducted in the constant temperature "All-Weather Room" chamber at the Aerospace Medical Research Laboratory. Air motion turbulence within the chamber varied in flow rate up to 8 meters per minute. The overall noise level within the chamber was 69 dB. The ventilating helmet was a round, double-walled, plexiglass chamber into which air was introduced through insulated tubes. A rubber neck ring provided a positive seal between the helmet and subject. Air was introduced through a perforated ring at the base of the helmet at 5 cfm. The weight of the helmet assembly was counterbalanced and was not borne by the subject.

Three measurements of mental arithmetic performance were recorded for each test. Four measurements consisting of four replications each for both position compensation and rate compensation tracking were employed. Five sets of 15 choices each comprised the reaction time measurements.

The mental arithmetic task was a subject-paced sequential addition and number comparison paper and pencil design. The subject was required to (1) note a left-appearing one- or two-digit reference number, (2) add an adjacent line of 12 single-digit numbers sequentially from left to right until the sum equalled the reference total, and (3) strike a line through the last digit included in the sum. This procedure was repeated by the subject through the 3-minute task duration. The mental arithmetic task was the first performance task administered at each trial, begun at 5 minutes after entering the chamber. It was repeated at +29 minutes and again at +63 minutes. The dependent variable used for analysis was the ratio of the number of correct sums to the total number of problems attempted.

The choice reaction time task was experimenter-paced, stimulus-controlled response, choice reaction time measurement of a 1:1 mapping of stimuli onto responses. The experimenter illuminated two, four, or eight lamps in a balanced array according to a predetermined sequence. The stimulus lamps were illuminated for approximately 3 seconds whereupon the experimenter extinguished one lamp. On observing one of the lamps extinguished, the subject removed his finger from a null switch and depressed the switch corresponding to the extinguished stimulus lamp. Depressing the correct switch extinguished the remaining stimulus lamps. Two dependent variables were measured from the subjects' response. These were reaction time, which represented the elapsed period from extinguishing the lamp until the subject moved his finger from the null switch, and and movement time, the period required by the subject to move his finger from the null switch and depress the response switch. Reaction time and movement time were recorded to the nearest millisecond.

The signals for the two tracking tasks were presented to the subjects on a 4-inch cathode ray tube mounted at eye level approximately 50 cm. from the eye. Tracking control was afforded through a force stick. Both the position compensation tracking and the rate compensation tracking task required the subject to attempt to retain a diverging signal within view on the display. The tasks were single-axis, closed-loop divergent systems where the divergent was constantly varied on a ramp input. The task was made inherently unstable due to inclusion of a positive error-rate feedback loop. In each case, the degree of instability was small at the start of the task but increased steadily during the course of the task performance until the signal was lost from view. The point at which the subject's error exceeded the scale of the display was taken as the measurement of task performance. The dependent variable used for both tracking tasks was an estimate of the subject's effective time constant. The value was the recriprocal of the instability present when control was lost. It represented an estimate of the subject's neuromuscular reaction time delay, lag effects of midfrequency neuromuscular dynamics, and a nonlinear remnant.

SUMMARY OF RESULTS

MENTAL ARITHMETIC

No significant effects were found for preexposure performance. Exposure performance ANOVA contained an interaction term for heat and time passage within the test which was significant at the 10% level. Simple effects test performed on the interaction revealed differences on the final performance task when the subjects were under heat stress. At that point, mental arithmetic accuracy declined in the heat.

REACTION TIME

Preexposure reaction time performance ANOVA confirmed that the subjects responded with different time periods for the three levels of information content in the task stimuli. This difference was significant at the 1% level. Further tests on this using the Newman-Keuls procedure revealed significant differences between all three levels of information content. Responses to the one stimuli were shortest and to the three bits stimuli were longest. There was an indication of a diurnal influence at work in the preexposure measurements. However, none of the tests of the diurnal effect reached a level of significance below the 10% level. This was not considered adequate to reject a null hypothesis that morning performance did not differ from afternoon performance.

The ANOVA of reaction time performance during the exposure tests revealed three Within Subjects main effects, two 2-way interactions and three 3-way interactions to be significant at the 5% level or less. Where appropriate further tests on the main effects were performed using the Newman-Keuls procedure. Further tests of the interactions were performed through the determination of simple effects.

One of the Within Subjects main effects was for Bits, the information content of the stimulus. This was significant at the 0.1% level. The results paralleled those experienced wth preexposure testing; i.e., responses to the three bits stimuli were generally longest. There was also a two-way interaction of Heat x Bits and two three-way interactions of Heat x Bits x Time.

The main effect for Heat was significant at the 5% level. In general, responses tended to be faster in the heat conditions than in the benign conditions. There were two 2-way interactions involving heat; these were Heat x Bits and Heat x Time. There were two 3-way interactions involving heat. These were Heat x Ventilation x Time and x Bits x Time.

The third main effect was for the passage of time during the exposure tests; this was significant at the 5% level. Reaction time responses tended to be slower towards the end of the tests than in the beginning.

The Heat x Bits interaction was significant at the 5% level. The Heat x Bits x Time interaction was significnat at the 0.5% level. These results indicated that responses tended to be faster in the heat until the close of those tests. During the last performance period under heat, the responses to three bits stimuli were markedly slowed by the heat stressor.

The Heat x Ventilation x Time interaction was significant at the 5% level. The Ventilation x Bits x Time interaction was significant at the 0.5% level. These results indicated that ventilating the head under heat tended to counteract the heat effects so that performance was essentially no different from that in the benign condition. When the head was ventilated in the benign state, responses to one bit and two bits stimuli were appreciably slowed during the final two data collection time periods.

Further analyses of reaction time data were accomplished to examine subject information processing. Least squares regression analyses were prepared for data collapsed across the diurnal levels for each subject at each condition and time block. The independent variables used for the regressions were the stimulus information content levels; the dependent variable was the observed reaction times. The slope values represented the change in reaction time in milliseconds per bit of information content. The regression slopes were subjected to analysis of variance. Two significant Within Subjects effects were revealed. These were the Conditions main effect and the Conditions x Time interaction. The interaction term was further tested through the determination of simple effects.

Three significant simple effects were found, all significant at the 1% level. These were differences in performance between conditions during the final measurement period and differences in time for the benign with head ventilation and the heat stress conditions. These simple effects implied that significant differences in the slope values appeared during the final measurement period for these two conditions. The simple effects also provided further explanation for the conditions main effect which was significant at the 5% level, and for the Conditions x Time interaction, significant at the 1% level.

Further analysis of the effects over time on the reaction time slopes was accomplished through the determination of the goodness of fit of three polynomial regressions for each of the thermal exposure conditions. In the benign ventilated condition, both linear and quadratic regressions provided descriptions of change and information processing performance which were significant at the 1% level. These confirmed earlier results that the change in information processing performance observed during the final measurement period was significant. Moreover, they indicated the effect was preceded by a noticeable change in performance approximately 48 minutes after onset of exposure. The high temperature stress condition polynomial regressions were significant for linear regression at the 5% level and for cubic regression at the 1% level. These indicated the significant impact arising from accumulated insult of the thermal stressor during the final time period and an earlier insult which appeared during the second time block. Although this earlier change was not statistically significant, the regressions suggested an early thermal insult impact on subject performance which did not show further effects until shortly before termination of the exposure.

MOVEMENT TIME

The preexposure movement time ANOVA revealed one three-way interaction, Condition x Bits x Time, to be significant at the 5% level. Simple effects tests were prepared for this interaction. Subject response speed was somewhat faster for the one bit stimuli during the second set. Response patterns to two and three bits stimuli were inconsistent. In general, responses to the three bits stimuli showed greater variability than did the responses to the one bit or two bits stimuli.

MOVEMENT TIME DURING EXPOSURE

Analysis of variance of exposure movement time revealed two significant Within Subjects main effects, Bits at the 5% level and Ventilation at the 5% level. Two two-way interactions were also significant. These were Diurnal x Heat, significant at the 5% level; and Heat x Ventilation, significant at the 0.5% level. Further tests on the bits main effect were made using the Newman Keuls procedure. Simple effects were determined for the significant interaction terms.

The Bits main effect indicated that responses to one bit stimuli were slowest. They differed from the two and three bits responses at the 10% level. There were no significant differences between two and three bits responses. The simple effects tests for the Heat x Ventilation interaction revealed that ventilation had a significant impact on movement responses in the high temperature conditions but none in the benign. These findings clarified the Ventilation main effect. Wearing the ventilating helmet increased movement times of the subjects under both benign and heat ventilated conditions. However, this time lengthening was significant only under the heat ventilated condition. Simple effects analysis failed to support the significance of the Diurnal x Heat interaction.

THE TRACKING TASKS

Analysis of variance of the effective time constant measures for the two tracking tasks during the preexposure periods revealed one significant main effect and one significant two-way interaction term. The main effect was for task difficulty which was significant at the 5% level. The interaction term was for Diurnal x Order (task difficulty) which was significant at the 1% level. Simple effects were determined for the interaction term.

The task difficulty main effect finding was substained by the simple effects tests. Rate compensation tracking was more difficult than position compensation tracking. Simple effects for the interaction revealed that rate tracking was better in the afternoon than in the morning; a result significant at the 5% level.

Analysis of variance of tracking during exposure found the task difficulty and diurnal influences seen with the preexposure performance repeated. In addition, the factor of time passage during the tests was significant at the 1% level. A further ANOVA was prepared for each tracking task separately.

The ANOVA for the position compensation tracking task revealed only the Within Subjects main effect for Time to be significant. It was significant at the 1% level. Newman-Keuls tests showed performance at the end of the tests differed significantly at the 5% level from performance through the first three time blocks.

The rate compensation tracking ANOVA revealed significant Within Subjects main effects for Diurnal (at the 5% level), for Heat (at the 10% level), and for Time (at the 0.1% level). Further tests for the Time effect were made using the Newman-Keuls procedure. Rate compensation tracking was significantly better in the afternoon. This had previously been observed with preexposure data. Performance in a heat environment was worse than in the benign conditions. The time passage effect revealed that passage of 20-25 minutes time caused a significant performance decrement in general.

CONCLUSIONS

Performance on all tasks showed the effects of the passage of time. The effect was one of worsening the performance which was probably due to the gradual onset of fatigue. The subjects' information processing capabilities, as indicated by reaction time responses, also generally showed this fatigue effect. However, the onset of fatigue was not pronounced in the benign and heat ventilated tests. In these conditions, the changes in information processing due to the passage of time was generally in the direction of deterioration, although the extent of that was not statistically significant.

Performance on the reaction time and rate compensation tracking task was affected by the time of day during which they were performed. The preexposure reaction time afternoon performance was better than morning performance. This was significant at the 10% level in the diurnal main effect and in two diurnal interactions. Rate compensation tracking was also better in the afternoon. The differences in performance attributable to this diurnal influence were probably related to arousal level differences in the subjects. The body temperatures of the subjects were slightly higher in all afternoon tests than they were in the morning tests.

Performance was apparently influenced by the arousal level of the subjects. This was seen not only with the diurnal influence discussed previously but also showed up in analysis of mental arithmetic and reaction time task performance. Poulton (1970) said that a heat stressor tends to increase speed and decrease accuracy. This was clearly seen in the subject's performance on the mental arithmetic task. Accuracy declined in the terminal stages of the heat stress conditions. Productivity in terms of the number of problems attempted was increased in the earlier stages of heat exposure. This was probably related to core temperature elevations of approximately 0.32°C and greater. However, when the work of others is considered, it is probable that arousal level influences on mental arithmetic accuracy cannot be directly related simply to core temperature change. Involved at least is a progressive influence and perhaps other physiological indices are involved. The nature of the relationship could not be determined from this research. The speed of choice reaction time responses also increased in heat. The corresponding change in accuracy did not appear, however. This influence of arousal differences on information processing to choice reaction time performance held throughout for responses to one bit and two bits stimuli. It held for 50 minutes for responses to three bits stimuli. Thereafter, responses to the greater information content were slowed by the over-arousal effect of environmentally imposed heat on the body.

The arousal level influenced was further substantiated by examination of the performance in the benign ventilated condition. Here the passage of time related to a gradual reduction in body temperature, probably caused the lengthening of responses to the one and two bits stimuli which was observed. This probably resulted from increasing under-arousal. This phenomenon was not seen with responses to three bits stimuli; however, three bits stimuli tasks, due to their complexity, tend to be arousing. This may account for the differences in the influence on performance. The nature of the under-aoursal, as with the nature of the over-arousal, cannot be directly related to the simple index of body temperature. It involves at least the gradual onset of the influence over time.

Mental arithmetic accuracy was sensitive to the heat stressor employed. Mental arithmetic accuracy was sustained unaffected for at least the first 30 minutes under all conditions, but did deteriorate in the closing moments of the conditions involving a heat stressor.

The regression of reaction time measurement associated with the stimulus information content did not hold under all environmental conditions. In the benign ventilated tests, there was little difference in the response time towards the end no matter what the information content of the stimulus. In the final measurements of the benign ventilated tests, a negative slope was found. This indicated that reaction to higher information content was, in fact, faster than to lower information content. This probably resulted from the under-arousal of the subjects at those points in time. The use of cool air to ventilate the head was effective in ameliorating heat influences on reaction time performance. When so used, the cooling of the head tends to counteract the influence of the heat stressor resulting in the overall performance being quite similar to benign performance. This was not true where the head was ventilated in the benign condition.

The movement time component of choice reaction time showed no consistent relationship to the information level of the stimulus.

Position compensation tracking using effective time constant as the dependent metric was a very stable task. It showed the influence of fatigue but was not sensitive to the other variables in this study.

Rate compensation tracking using a ramp forcing function was a sensitive measure of investigation variables. It is clearly sensitive to diurnal differences and to fatigue effects of the passage of time. It may also have been sensitive to heat effects of the magnitude used in this research since heat was found to be significant at the 10% level. This may have been a result of the differences in arousal level induced by the environmental heat load on the subjects.

TABLE 22
MEAN RECTAL TEMPERATURE CHANGES

	Benign °C	Benign Ventilated °C	Heat Stress °C	Heat Ventilated °C
Preexposure Mean	37.07	37.05	37.04	37.03
Exposure Time min				
+5	−.19	−.46	−.12	−.15
+10	−.18	−.36	−.16	−.19
+15	−.20	−.34	−.08	−.16
+20	−.22	−.36	−.04	−.10
+25	−.21	−.37	00	−.11
+30	−.25	−.38	+.07	−.06
+35	−.27	−.39	+.16	−.01
+40	−.27	−.42	+.26	+.01
+45	−.30	−.44	+.33	+.05
+50	−.31	−.47	+.41	+.09
+55	−.33	−.48	+.54	+.18
+60	−.36	−.49	+.66	+.29
+65	−.35	−.50	+.70	+.32

RECOMMENDATIONS

Based upon this research the following four recommendations for further study are advanced.

Movement responses in a reaction time task towards a target switch may involve a two-step feedback corrective process by a subject. This was not apparent from this research; however, differences found in movement time responses to differing stimulus information levels suggests this may be a fruitful area for research.

Further research should be undertaken to attempt to define the physiological correlates of arousal level. There were strong indications that differences in performance could be attributed to arousal level changes. Such further study should employ sensitive metrics. The use of some sensitive brain function measurement technique might prove to be fruitful.

Unless a piece of research is aimed at detecting differences in performance due to a diurnal influence, this investigator strongly recommends that performance measures be taken on all subjects at the same time of day in order to reduce potential contamination due to diurnal variance.

Recommend future research involving tracking tasks be designed in such a way that subject describing functions can be derived. Moreover, strongly recommend that such tasks be so designed as to be specifically relatable to the potential application to which they may be related.

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